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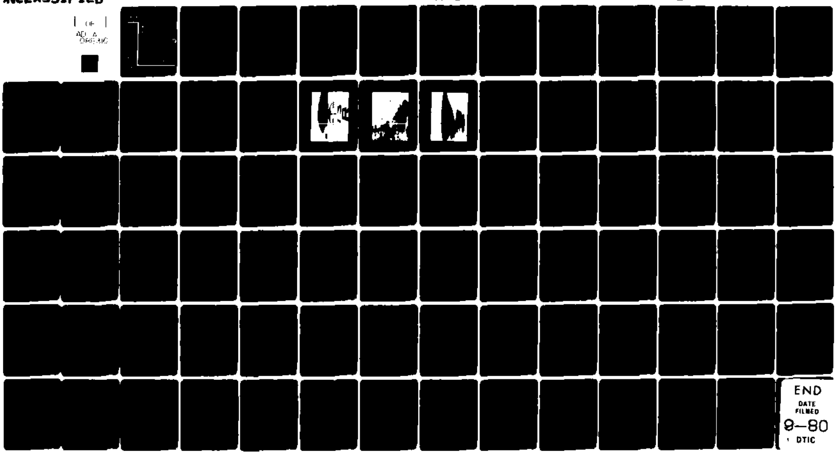

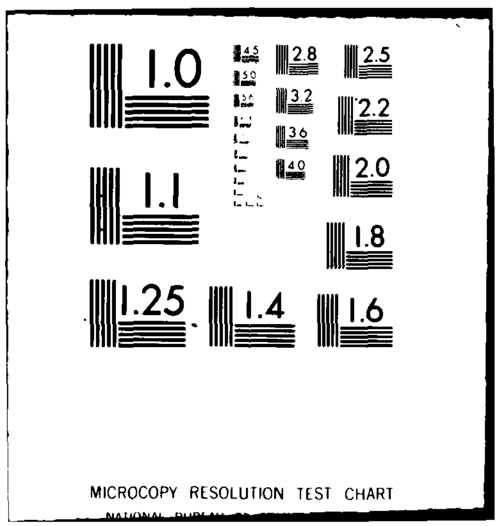
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AIR FORCE

HUMAN RESOURCES

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PSYCHOPHYSICAL CRITERIA FOR VISUAL SIMULATION SYSTEMS:
PHASE II — EXPERIMENTAL INVESTIGATIONS OF DISPLAY JOINTS AND SCENE INSERTS

By

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August 1980

Final Report

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This final report was submitted by Boeing Aerospace Company, Data Processing Technology, Seattle, Washington 98124, under Contract F33615-78-C-0012, Project 6114, with the Operations Training Division, Air Force Human Resources Laboratory (AFSC), Williams Air Force Base, Arizona 85224. Dr. Kenneth R. Boff was the Contract Monitor for the Laboratory.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the approach, procedures, and results of two psychophysical experiments to provide data useful in developing design criteria for visual simulation systems. The first dealt with the influence of the width of joints between display channels on the discrimination of vertical and rotational scene misalignment across the joint. The resulting information indicated that increasing amounts of rotation resulted in an increased percentage of correct detections. This anticipated result was not found for the displacement conditions. It was hypothesized that this unexpected result may have been caused by the counteracting effect of the Poggendorff visual illusion. The second psychophysical experiment dealt with the discrimination of rotational misalignment of scene inserts. Increasing insert size and increasing rotational

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misalignment produced increased detection performance. The 50% detection threshold occurring at 7 arc seconds of displacement between corresponding portions of the insert and surrounding scenes. Design tolerances based on these data are suggested.

FOREWORD

This report was prepared under work unit number 6114-22-03 by the Crew Systems organization, Data Processing Technology, of the Boeing Aerospace Company, Seattle, Washington. The work was done under contract F33615-78-C-0012 for the Simulation Techniques Branch of The Air Force Human Resources Laboratory (AFHRL) at Wright Patterson AFB, Ohio. Phase I of Psychophysical Criteria for Visual Simulation Systems was reported in February 1980 as AFHRL-TR-79-30.

We appreciate Dr. Doug Anderson's (AFHRL/ASM) support as Air Force manager of this contract. At the submittal of the first draft of Phase II, Dr. Ken Boff took over management of the program. We are especially appreciative of Dr. Boff's interest in this program and his help in seeing it through to completion. Dr. Lowell M. Schipper, Professor at Bowling Green University, reviewed our statistical analysis, while working with AFHRL/OT. We appreciate his critique and recommendations. Special thanks are due to Lt Col Daniel Wasserstrom, Chief, Aircrew Standards/ Evaluation, 62 MAW/DOV, McChord AFB, Washington, his coordinator Capt Jerry Newquist, and the 25 pilots who served as observers in these experiments. Their cheerful cooperation greatly facilitated our task.

We also wish to thank Helen von Tobel for her work in the collection of data, coordination with the individual pilots, assistance in data reduction, editing and manuscript preparation. Jeff Kosan and Sue Wilson, Boeing Aerospace Company co-op students from Wright State University and the University of Michigan, respectively, were most helpful in data reduction and preparation for computer analysis.

SUMMARY

This report covers Phase II of a contractual effort to provide psychophysical criteria for visual simulation systems. Phase I had indicated a number of areas that had insufficient data on which to base design criteria for displays. The experimental investigations reported here provide data that will assist in the specification and design of visual simulation systems in two of the identified areas: (a) the criteria for rotational and vertical alignment specifications of adjacent channels in multichannel displays as joint width or separation between channels is varied; and (b) rotational alignment specifications for high resolution inserts as a function of insert size, resolution differences, and scene characteristics.

In using these data, the conditions of the study must be kept in mind. The practical problems of experimentation within budget and time constraints impose limits on any psychophysical study which, to a greater or less degree, limit the extent to which the results can be applied to situations or conditions different from those studied. Conditions of the present studies which should be considered are:

1. Scenes were limited to daylight conditions.

2. Three scenes were used representing different phases of flight. While these scenes represent the state of the art in luminance and complexity for operational computer-generated image (CGI) systems, they do have limited capabilities with regard to these variables. The range of scene content (e.g., urban, agricultural, mountainous) was similarly restricted. The scenes were selected from the repertoire available in the Boeing simulator. They were judged by the investigators to be typical of on-the-runay, air-to-ground, and ground-to-air visual tasks.

3. Static rather than dynamic scenes were used.

4. To cover a greater number of dependent variables, an experimental design was selected which permitted only one observation per subject per condition. As a result, there is some increase in variability with a resultant loss of sensitivity; this does not appear to be a major problem because an analysis of variance showed all the main effects and many first-order interactions were significant.

5. The subjects were experienced USAF Military Airlift Command pilots. Two of the three scenes were selected to represent tactical situations. To what extent tactical pilots would have been more or less affected by the experimental conditions is unknown.

For the first study, one of five joint widths was used to subdivide the scene into forward and left forward juxtaposed channels. Variations in vertical displacement and rotational errors of the left channel scene were presented by slide projectors. Sixteen USAF MAC pilots from McChord AFB were asked to detect and identify the types of misalignments in 120 slides displayed on a translucent screen.

For the second study, insert sizes of 3°, 6°, and 12°, with and without raster line density variations, were shown to 16 MAC pilots. The insert scene was rotated in five steps from 0° to 2°. The pilots were asked to determine whether rotational misalignment was present and, if so, the direction of the rotation. The effects of joint-width scene differences, misalignments, or rotations, as well as most of their interactions, were statistically significant in ANOVAs dealing with categories of correct detection or of "aligned" responses.

Joint widths of different magnitudes altered the thresholds for the detection of just noticeable scene displacements and rotations. Joint widths equal to or greater than .25° of visual angle, masked detection of vertical displacements up to 1.4 arc minutes. However, this may be specific to the scene and joint used, as a portion of the masking may be due to the Poggendorff illusion. Oblique lines in the CGI scene, the slope of the joint from the vertical, the width of the joint, and the interactiong angles of lines in the scene may all act to mask or enhance the perception of errors in vertical alignment.

Narrow separations between display channels did not improve the discrimination of rotational errors. Joint widths greater than .5° assisted in the discrimination, particularly where the CGI included shade banding across the lateral extent of the scene. Rotational errors of 1° and 2° were discriminated above chance for all joint widths and scenes. If taken from these data, a specification for maximum rotational errors across multichannel displays would be at .5° rotation or less for joint widths of less than .5°. Scenes that include shade banding will make the tolerance limits for rotational errors more critical for joint widths greater than .25°.

The results of the scene insert study indicated that inserts with or without raster lines should not be rotated by an angle that produces more than 7 arc seconds of displacement at their perimeter; thus, the larger the insert, the less the tolerable angular rotation. The discrimination of rotation was positively correlated with the amount of rotation, describing a linear function when plotted against log degrees of rotation. Discrimination of rotation is highest with the scene undisturbed by raster lines.

Designers who anticipate using inserts that should not be discernible by rotational errors must develop systems that have less than 7 arc seconds of misalignment at the edge of the insert. These specifications would not apply to an insert accurately slaved to the behavioral axis of the eye. However, until such a system is developed and proved applicable, the specification previously discussed should be adequate for rotational error limits.

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INTRODUCTION

The importance of visual systems in simulation has been generally accepted for initial training of pilots, for approach and landing proficiency, for initial training in weapon delivery, and for air-to-air combat. However, each military task has imposed special requirements on the design of out-of-the-window scene generators and displays. Since 1973, the flexibility of computer-generated image (CGI) systems has drawn more and more interest as the operating systems have demonstrated both their effectiveness and reliability. The operational commands, meet the needs of their specific military tasks, have expressed a need not only for more simulators but also for ones with specialized CGI systems with wide field of view and infinity displays. The more accurately we can predict the requirements for and the effects of various design concepts, the more cost-effective we can make the procurement cycle.

The task of Phase I of this contract was to collect and abstract the information available in the literature on visual characteristics of flight simulator display systems and to investigate those areas where the information was incomplete or inadequate. An additional task was to suggest which information could be supplied by experimental investigations. The Phase I report (Psychophysical Criteria for Visual Simulation Systems, Boeing Document No. D194-10084-1, AFHRL-TR-79-30, Contract F33615-78-C-0012) indicated seven areas that could be investigated by psychophysical studies. This Phase II report is an account of the two experimental investigations selected by the Air Force for initial study.

The specific military tasks of air-to-air combat and air-to-ground weapon delivery impose very specific requirements for larger fields of view. An experimental simulator study (LeMaster & Longridge, 1978) was conducted by the Operation Training Division of the Air Force Human Resources Laboratory at Williams AFB. It included flying the T37B simulator cockpits with a display of seven cathode ray tubes with infinity optics providing a wide-angle field of view (300° horizontal by 150° vertical). Students were able to demonstrate an improvement in their bomb delivery performance as a function of larger fields of view. The pilot's task was to deliver the bombs on a bombing circle by executing dive angle approaches of 10°, 15°, and 30° with different lateral fields of view available to them. Results based on from 28 to 35 bombs per data point were plotted and indicate that when the field of view was 52°, the average circular error was about 162 feet. It decreased to about 136 feet with a 70° field of view, to about 120 with 90°, to about 116 with 110°, and to 115 feet with 130° field of view.

In air-to-air combat, the fighter pilot must be able to scan as large a part of the visual field as is possible. It has been shown on the maneuvering range that the pilot who has the first visual acquisition of the other aircraft has a distinct advantage because the position and attitude of the foe can be obtained from this visual sighting. The pilot may use radar or infrared sensors to determine which way to look, but it is the first visual contact that gives the advantage in air-to-air combat. These data have impressed those commands involved with air-to-air combat, increasing their interest in systems having large fields of view. However, there is a penalty to pay: the expansion of the field of view is obtained only with the increased computer capacity required to maintain an equal resolution as the field of view is increased.

With CGI systems, the method of increasing the field of view is to put display channels adjacent to each other or stacked one above the other with joints or gaps between these separate channels. In those systems providing an infinity window by the use of a cathode ray tube, beam splitter, and spherical mirror, the technique used has been to increase the lateral field of view by putting the channels juxtaposed (as in the Messerschmitt, Boelke, and Bohm system) with a forward channel and right and left forward oblique channels. These channels are separated by about 1/8°. This narrow joint or gap also has been used in the Conductron and Redifon 747 simulator's Compuscenes between two channels: i.e., a forward and an oblique for the captain and first officer's positions. The method used in the ASPT involves a pancake window with separations that are for pentagons. These joints are slightly larger than those in the two systems mentioned previously. Narrow separations between these channels provide a continuous scene which is preferred by the operational pilots.

The same preference for narrow separations is not true for maintenance people, who find that pilots can discern misalignments or mismatches in chromaticity across the narrow separations between the channels. "Malfunctions" are reported much more frequently for narrow gap systems than for large gap systems because the visual system is a ratio system and makes the best discrimination when it has juxtaposed comparative stimuli. Therefore, mismatches in color, which would not be noticed if the two displays were 20° apart, are easily recognized when they are juxtaposed. This is also true of alignment of horizontal lines, such as the horizon and the lines separating fields, contours, buildings, and shapes that are representative of target patterns. Consequently, the accuracy of the visual systems, in representing true perspective aligned across multiple channels, becomes much more critical when the gap between the channels is narrow. The designer of new systems must know the specific requirements for accuracy when planes and objects in the visual scene are to be represented across the separations between channels.

A search of the literature reveals a good deal of experimental evidence for improved discriminations of displacements, rotations, or changes in color as a function of decreased space between visual targets. However, no data were found that specify the accuracy with which the designer of the simulator visual system must specify channel alignment, especially when there is a pictorial dynamic scene.

The objective of Experiment 1 is to establish the influence of the width of separation between channels (called gaps or joints) on the requirments for the alignment of systems, insofar as a vertical displacement or a rotation between visual channels is concerned. A problem comes from the paradigm of the air-to-air search, as well as the air-to-ground target acquisition. The problem is that it would be desirable to have the large field of view as well as high resolution. One possible solution is to present the aircraft (the other target) in a small insert of high resolution. For example, if the image of the other aircraft could be presented in a 10° x 10° insert generated on a cathode ray tube which had a 1,000-line capability, the actual line by element resolution could be close to the resolution of the eye, or less than 1 arc minute. However, if that insert was easily recognizable as an insert, especially as the one containing the target, then the search phase of target acquisition would be inappropriately simulated. That is, pilots would not have to spend the large amount of time normally taken in visual search, as they would immediately know where to look for the other aircraft by recognizing the 10° x 10° insert. This also would be true in air-to-ground target acquisition; however, an additional aspect of air-to-ground target acquisition is the need to simulate the immediate surrounding area of the target with the same resolution as the target itself.

The similarity dimension of target versus surround is highly correlated with target acquisition. The 10° x 10° sector could be easily recognized when a dissimilarity exists with the surrounding field, thus, the search function for the target is minimized by supplying the pilot with any feature that defines the insert. One way of avoiding this problem is to have a large number of inserts, most of which simulate the one containing the target. This strategy is useful only when the target itself is the only just noticeable difference among inserts.

In Experimental Study 2, we looked at the question of whether the raster lines of an insert, that were slightly rotated from the general field would be a just recognizable cue as to the insert containing the target. And if so, at what degree of alignment would the rotation not be noticeable?

EXPERIMENT 1
EFFECTS OF SCENE COMPLEXITY AND SEPARATION ON THE DETECTION OF SCENE MISALIGNMENT

BACKGROUND

In the real world of flight, the visual scene external to the aircraft is separated into channels by the existence of structural members necessary to maintain the integrity of the airplane. Generally, these separations between the transparencies in the aircraft are narrow enough that a pilot by moving his head from one side to the other, can look around this gap to see the occluded portion of the real world. In simulation, however, the display channels are generally more restricted in field of view than are the windows in real aircraft. To represent a full field of view requires the use of multiple channels and artificial joints which are coincident with, or separate from, the structural members normally associated with that particular aircraft. Although a pilot's head motion is not restricted in the simulation, the visible area behind the post or joint is limited. The limitations in the beam splitter mirror system are generally the angular extent of the mirror, and juxtaposed display joints limit the look around to a head motion equivalent of 3°. In the pancake window, the head motion is primarily limited by the amount of distortion imposed as the head is moved out of the viewing volume.

The perceptual factors involved in perceiving misalignments should be common for any separation between channels if they have a common orientation in the visual field. One factor is the recognition of displacement of discontinuity in a line segment that extends through a joint either as part of the scene or as the raster lines for line scan systems. It is anticipated that this perceptual task will primarily involve vernier acuity. A second perceptual factor will be the recognition of imposed curvature on a straight line, or the degrees of rotation between channels representing portions of the same scene. In addition to vernier acuity and the detection of rotation, other display factors that affect perception of misalignments include stimulus separation, contrast sensitivity, display resolution, luminance intensity, and stimulus motion.

THE PROBLEM

Two hypotheses will be tested in this experimental investigation:

Hypothesis 1: The tolerance for scene misalignment is greater if the joint separation between two displays is wider.

Hypothesis 2: This tolerance will vary with the dimension of scene complexity.

The experiment to test these two hypotheses has been designed to provide some threshold measures for the detection of scene misalignments with (a) rotation centered in the vertical middle of the display joint, (b) vertical displacement of the left half of the scene, (c) display joints of various widths, and (d) scenes with differing levels of complexity.

METHOD

Apparatus

The G. E. Compuscene was used for the displays. Ten 4" x 5" color transpositives were made from the pilot eye position (left seat) in the 747 (Redifon) simulator, using a 4" x 5" Crown Graphic camera with an Optar 135mm lens. This combination of format-size and focal-length of lens required that the lens be positioned 3" behind the eye reference position. However, this is well within the minimum distortion area of the infinity image display eye reference volume.

Ten photographic transparencies were made with a minimum of three each representing three classes of Air Force tasks. The first was approach-and-landing, the second was air-to-ground target acquisition and the third was air-to-air combat. Three of the ten photographs were selected for the stimulus materials. These three 4" x 5" photographs were copied to make 35mm slides with a vertical black strip separating the left and right portions of the scene. In each slide, the left hand scene (16° of the total 42° horizontal field) was rotated or displaced to produce desired misalignments at the joint. Four levels of rotation were used and when displacements were present, four levels were built into the 35mm slides.

For rephotographing, a Canon A-1 camera was used. This camera has a separate lever allowing double exposures. This was necessary because the photograph of the forward scene had to be one exposure and the photograph of the misaligned "left oblique" scene had to be the second exposure. This camera was mounted on the movable carriage of a large Mann Comparator, which permitted its movement in X and Y to an accuracy of .001 millimeter. The camera was facing downward toward the trans-illuminated stage of this comparator. Beneath the stage a self-metering strobe light illuminated a diffusion reflector at 45° to the horizontal beam of this strobe light, and this diffuse light was reflected upward through the transparency toward the camera. The transparent stage of the Mann Comparator was covered by an outline mask representing the 28° x 42° area of the final transparency. The 4" x 5" transparency was registered above this outline frame.

When Mask A was positioned over the transparency on the comparator stage, the "side window" portion of the image on the transparency was occluded, permitting the "front window" portion to be imaged on the film in the camera. When Mask B was positioned over the transparency, the "forward window" view was occluded, allowing the "side window" view to illuminate the film in the camera. A middle strip of the transparency on the comparator stage was always blocked, either by Mask A or Mask B, and this strip corresponded to the dark area corresponding to the gap in the scene in front of the pilot. Five sets of these masks permitted the dark area between two scenes to be represented by .125°, .250°, .50°, 1.0°, and 2°. The camera was designed to release the film for the second exposure, but it did permit some film movement, and the tensions on either end of the film strip did impose some variations. These features are reviewed in Appendix A. Changes in alignment, either by vertical displacement or rotation were imposed, by moving the stage beneath the camera.

A total of 120 slides were made and projected on a translucent screen in the data collection phase. Examples of some widths of joints and the three scenes are included in Figures 1, 2, and 3.

Experimental Design

Figure 4 depicts the basic design for the main investigation of the effect of scene complexity and separation on the detection of scene misalignment. The design is basically a "double" 3 x 4 x 5 factorial with the following three independent variables:

1. Amount of scene complexity - three levels which include a distant "runway" scene, an "approach-to-runway" scene, and a "ground-to-air" scene. The dependent variable is the number of misalignment detections recorded as the number of correct recognitions of the type of misalignment (displacement or rotation).

2. Amount of scene misalignment (either displacement or rotation) four rotations which were 0°, .5°, 1.0°, and 2.0° from center of joint and four levels of displacement which were 4.7, 14.1, 42.3, and 84.6 arc seconds of visual angle.

3. Width of display joint - five levels which were .125°, 25°, .50°, 1.0°, and 2.0° of visual angle, as viewed by the observer.

Observers

Sixteen pilots from McChord AFB were selected to serve as observers in the experiment. They were screened for vertical and lateral phoria and had a visual acuity of at least 20/20 corrected.

Procedure

Each slide was presented for approximately 3 seconds, and after the response of the pilot, the next slide was presented. Each observer judged (a) whether a misalignment existed and (b) the kind of misalignment. The slides were shown in random order distributed over two Kodak Carousel trays. Each observer saw 120 slides, with a short set of training slides preceding the test session. For half of the subjects, one tray was presented first, and for the other half, this tray was presented second.

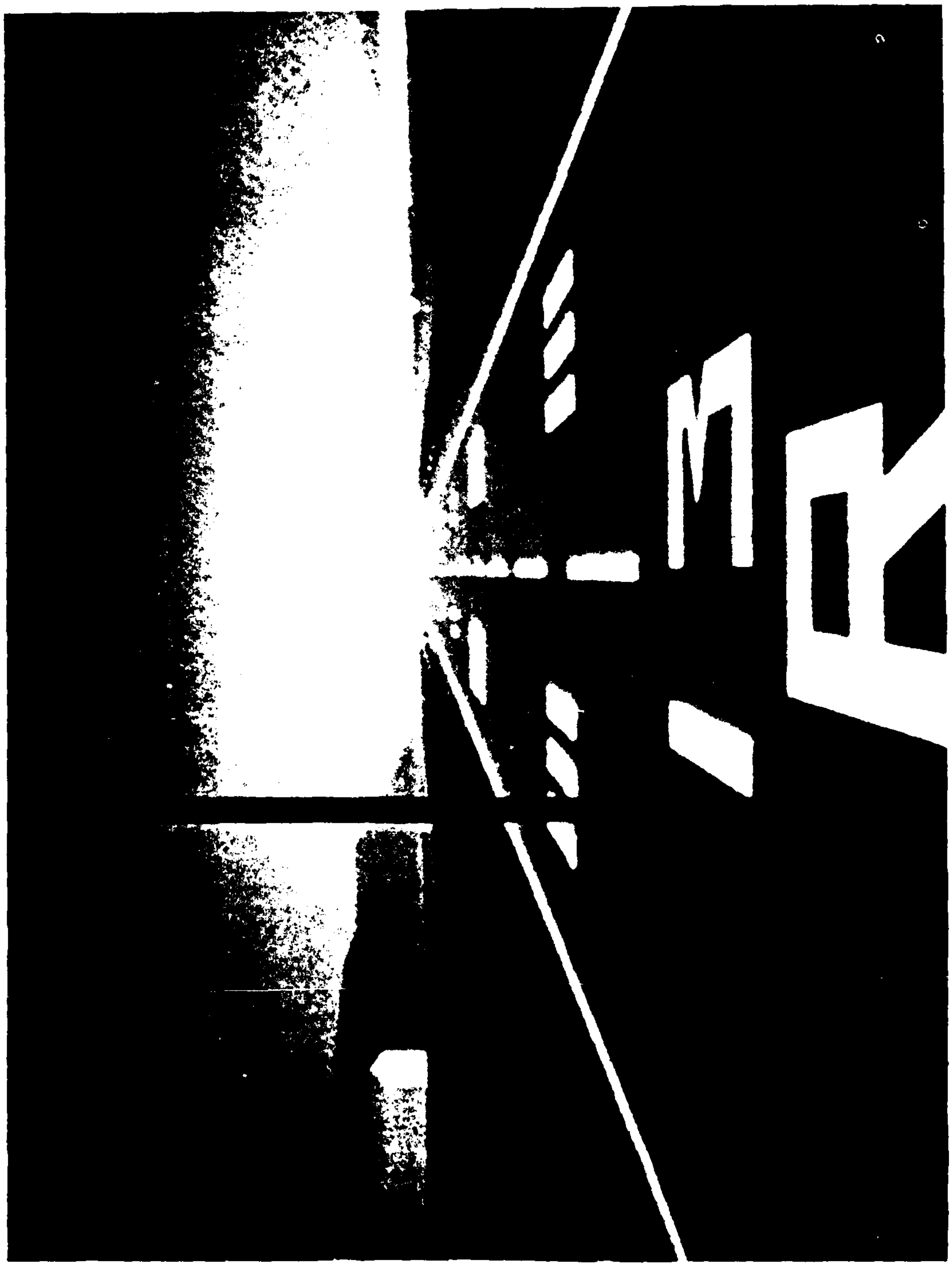

Figure 1. Example of scene 1 and rotations as a function of joint width.

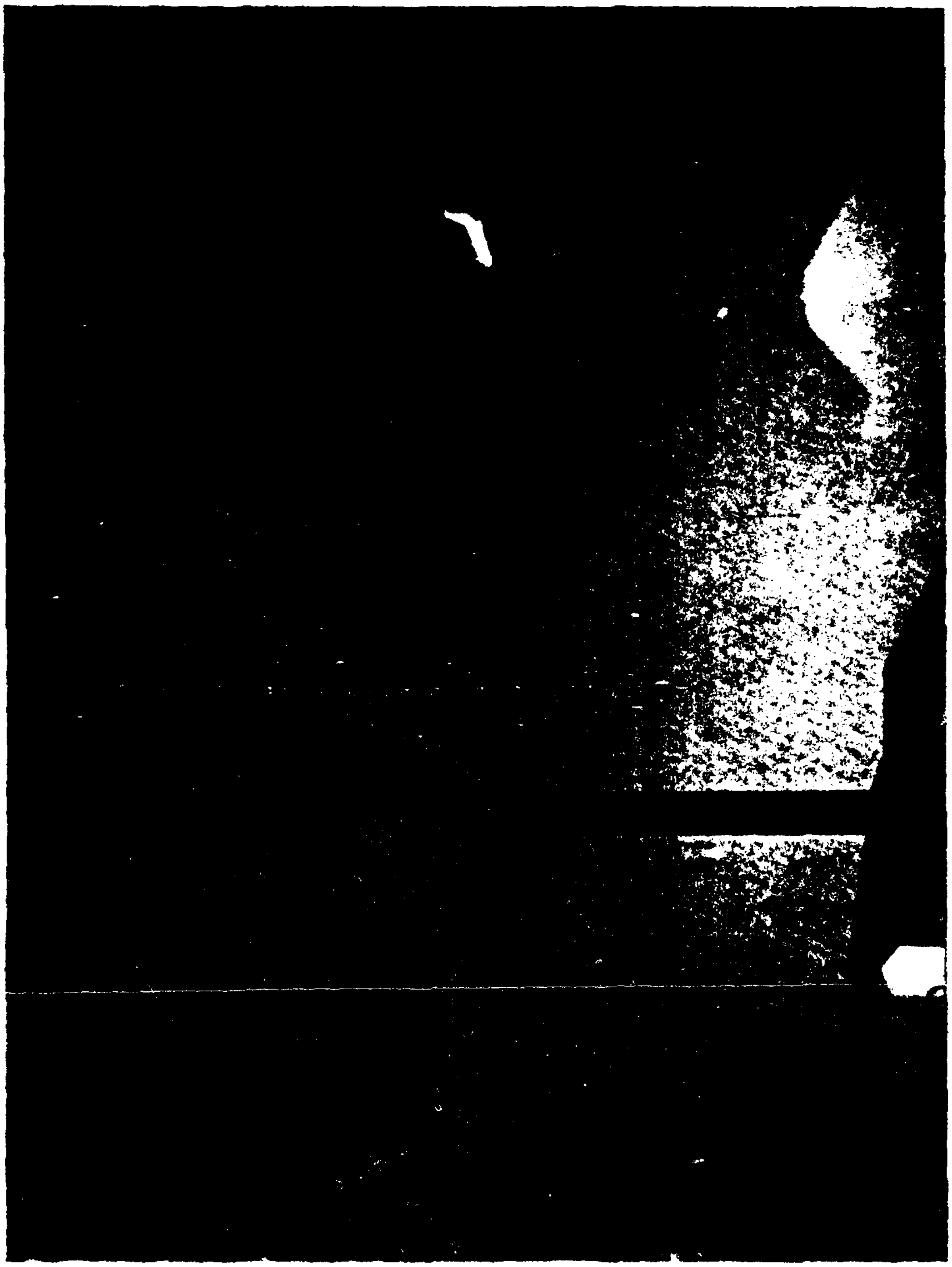

Figure 2. Example of scene 2 and displacement as a function of joint width.

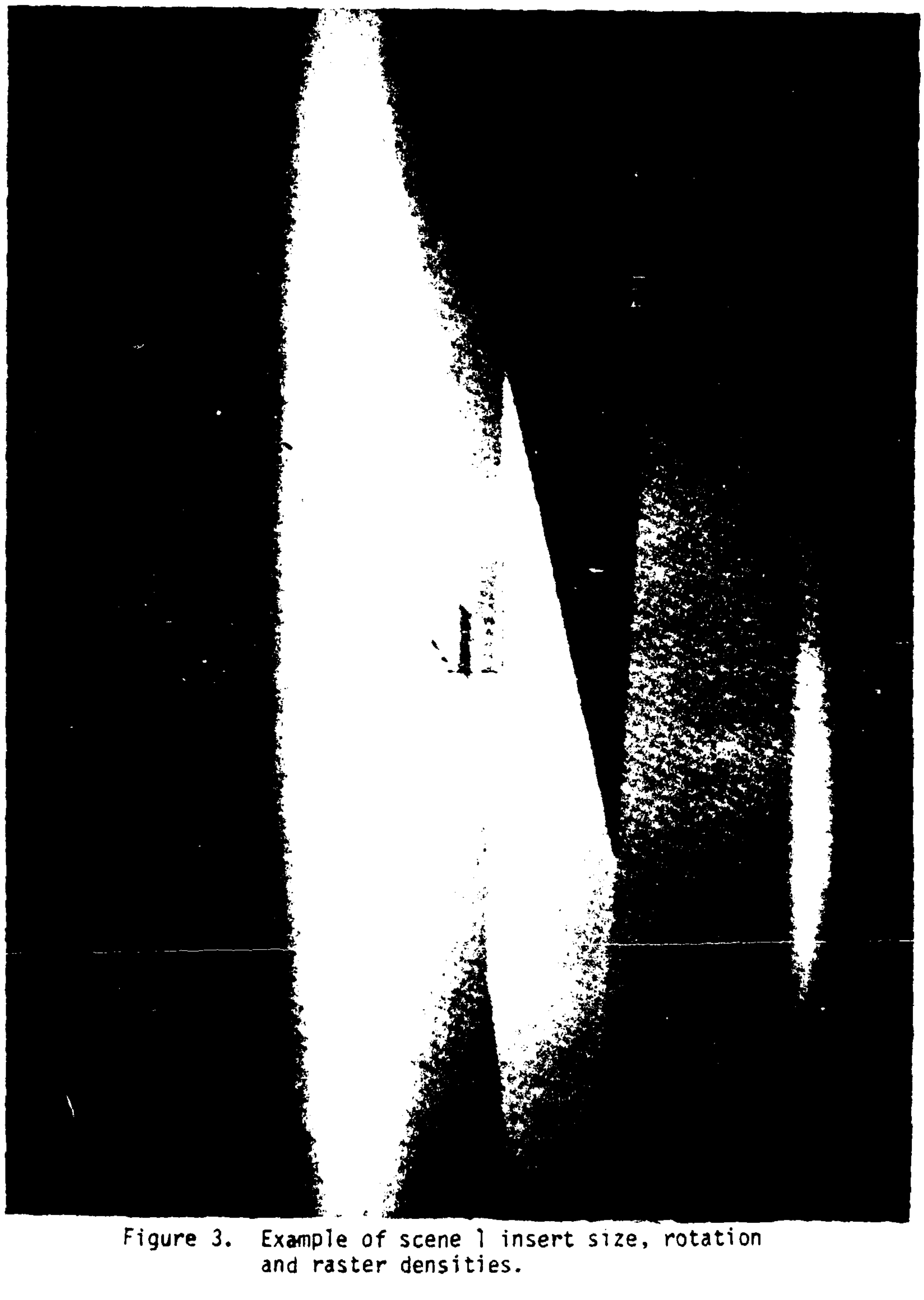

Figure 3. Example of scene 1 insert size, rotation and raster densities.

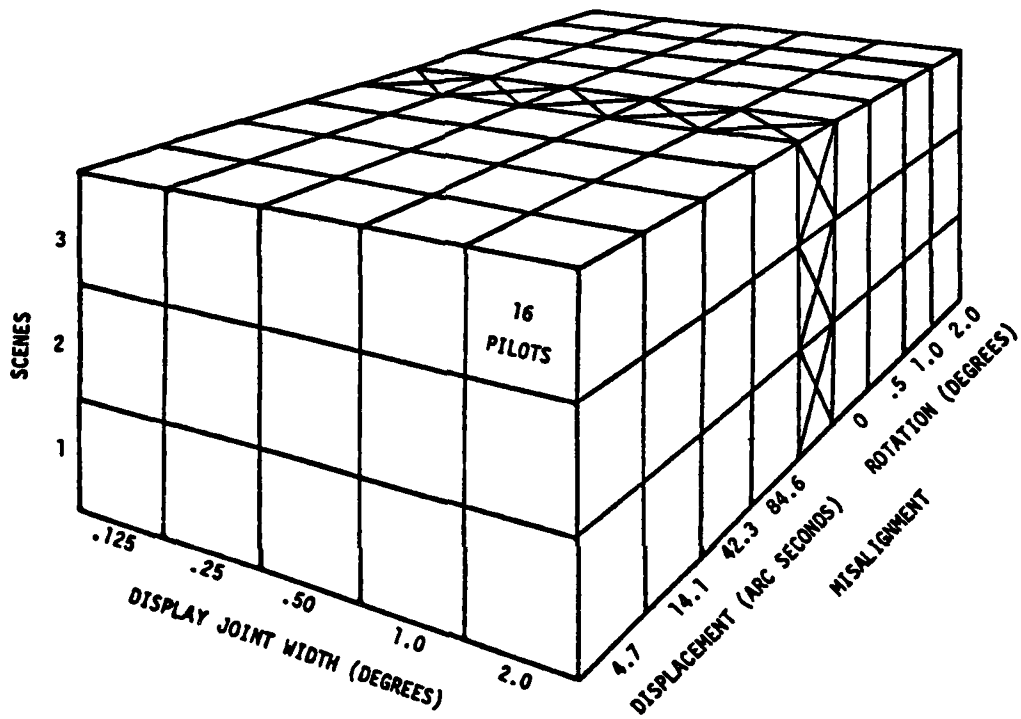

Figure 4. Experimental designs of investigations on the effects of joint width.

The data for the study of the effects of scene complexity and separation on the detection of scene misalignment were collected at McChord AFB. The pilot was seated 86 cm from a Polacoat 65 percent transmission translucent screen. The projected image size was 66 cm in width, or 42° of angular width. The room illuminance was approximately 3 foot lamberts, and the projected image was not modulated between the projector and screen. The Kodak Carousel, a digitally controlled projector, permitted sequential presentation of the slides, recall of a prior slide, or selection by tray number.

Instructions to the Pilots

> This is an experimental investigation of aspects of visual scenes and display for possible future use by the USAF. The Boeing Aerospace Company is conducting this experiment as part of a contract sponsored and monitored by the Air Force Human Resources Laboratory Operations Training Division, Wright Patterson AFB, Ohio.
>
> The techniques of displaying fields of view larger than 30° x 40° generally will include some divider between two or more video channels. This separation between displays, or joints, may vary from a few arc minutes to 20°. The narrower the joint, the more of the visual scene is available to pilots without changing their head position. However, the more narrow the joint, the more critical the alignment of the scene, the matching of colors, and the minimizing of distortion must be to appear correct for the flight instructor, the trainee, and the simulation manager.
>
> The problem is to determine the "just-noticeable" and "just-not-noticeable" thresholds for linear displacement and rotation of the left portion of this scene relative to the forward portion of the scene. The data will be useful as specifications for future equipment designs. USAF pilots are the population that will use the future designs of visual scene displays. It is desired that you, as one of 16 pilots, represent this larger population. In this situation, then, you represent the "measuring tool," and your results are correct if you represent all other pilots like yourself. All the data will be treated and reported as group data, and an individual's performance will not be identified.
>
> You are asked to view 120 slides and judge whether the left-hand segment is displaced, rotated, or aligned with the right segment. The width of the joint, the black vertical divider, will vary in width. The vertical displacement and the rotational amounts will vary. The computer-generated scenes will be three in number. The following sample slides will show you varying amounts of each of these paramaters.

The experimenter will step the projector the the next slide on your response, and you may proceed at your own pace. However we recommend spending from 3 to 5 seconds per slide. Each five slides will be followed by a dark slide, the purpose is to assure the experimenter that he has not gotten out of phase with your responses.

The procedure was to present 60 slides in the first half of the session, allow a rest, and then proceed with other visual testing. Following the rest interval, the second 60 slides were presented. The experimenter recorded all responses as aligned, displaced or rotated.

Data Analysis

When data collection was complete, the following analysis tasks were performed: (a) the raw data was transferred to punched cards for analysis by a Digital VAX 11 computer, (b) some of the data were hand-scored and a preliminary summary completed for use in cross-checking the computer analyses and for an early determination of data trends, (c) the raw data was scored by two computer software routines, (d) an analysis of variance was performed on the data for two performance categories (described below), and (e) a general graphics software package was used in conjunction with a Digital PDP 11/70 computer to provide plots of data means for interpretation and documentation.

For each subject, two measures were computed: (a) the percentage of correct detections of the various types of misalignments when they were present and (b) the percentage of "aligned" responses (no misalignment detected) made to all conditions presented. These categories did not represent precise reciprocal functions. Data were collected on the displaced and rotated scene misalignment conditions in a single session with each pilot and therefore three categories of responses were available to the pilots: "aligned," "displaced," and "rotated." Thus, a slide that had a displaced misalignment could be erroneously responded to as either "aligned" or "rotated." The rotated response would not contribute to either the "correct detection" or "aligned response" categories.

Coincidentally, the latter category represents both correct and incorrect perceptions: when the response is to any of the conditions containing some misalignment, it is an erroneous response; but when it is to a condition in which there is no misalignment, it is a correct response. However, these responses are grouped together because they both represent situations in which the observer is unable to detect any misalignment in the displayed scenes. This category may be relevant to the system designer since, as the percentage of "aligned" responses begins to fall off with increasing misalignment, and the observer starts to make correct detections, a design specification for misalignment can be selected based upon the impact of the detection of such misalignment upon the training task.

As implied here, the scores in these performance categories consisted of binary or dichotomous values (0 or 100 percent), indicating that the response either was (100) or was not (0) a correct detection in one case, or an aligned response in the other. Such data are not generally subjected to analysis of variance techniques because of the obvious violation of the assumption of normally distributed data. However, it is felt that sufficient justification for this application has been found in the statistical literature to warrant its use. The primary advantage of the analysis of variance is in the examination of the various interactions of the independent variables, some of which are vitally important to the task of establishing design criteria. A summary of the literature reviewed and rationale followed in applying the analysis of variance technique, is provided in Appendix B.

RESULTS AND DISCUSSION: DISPLACEMENT

Misalignment of Scenes

The main effect of this experiment is called "gap width" or "joint width." The separation between two channels in the video system is of particular interest to the Air Force. The Air Force is particularly interested in these data as they apply to the design requirements for alignment of two channels representing a common scene. This experiment tests the hypothesis that the "likelihood of scene misalignment increases if the 'joint' or separation between the two displays is wider."

The ANOVA on the percent correct detections of displacement indicates that all main effects, joint width, scenes, and displacement were statistically significant at a probability of less than .01 except for scene .05. (See Table 1.) This level of significance also was found for the three first-order interactions and the second-order interaction (designated S x J x D in Table 1). The significance level obtained indicates that the difference measure among the main effects and interactions might be due to chance only once in 100 replications of this experiment. A second ANOVA (Table 2) on the percent of "aligned" responses indicates that, with the exception of the main effect of displacement ($p < .05$), all main effects and inter actions were significant at the .01 level. The data from these two analyses will be used for this discussion.

The Effect of Separation or Gap Size

When plotted to show its influence on the percent correct responses, separation or joint width indicates that a separation of 0.25° or larger will mask displacements when all other variables are combined. Figure 5 indicates that a separation of 0.125° (-.9 log degrees) will result in 68-percent correct responses. Using the standard error of a percentage, assuming the distribution to be normal and interpreting this statistic for large samples, the confidence levels for each point on this graph would be plus or minus 6.7 percent with the probability of .95. The 68 percent correct responses at the .125° separation is significantly different from the average correct responses for each of the

Table 1. ANOVA Summary for Percent Correct Detections of Scene Displacement in the Display Joints Study

ANOVA TABLE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM /n-1	MEAN SQUARES	F
SCENE	28770.83	2/30	14385.42	F = 4.70*
JOINT WIDTH	197666.67	4/60	49416.67	F = 24.50**
S x J	109145.83	8/120	13643.23	F = 10.22**
DISPLACEMENT	29750.00	3/45	9916.67	F = 8.13**
S x D	91312.50	6/90	15218.75	F = 8.35**
J x D	111083.33	12/180	9256.94	F = 6.08**
S x J x D	186604.17	24/360	7775.17	F = 5.11**
PILOTS	143166.67	15		
S x P	91895.83	30	3063.19	
J x P	121000.00	60	2016.67	
S x J x P	160187.50	120	1334.90	
D x P	54916.67	45	1220.37	
S x D x P	164020.83	90	1822.45	
J x D x P	274250.00	180	1523.61	
S x J x D x P	548062.50	360	1522.40	
TOTAL	2311833.33	959		

* $p < .05$
** $p < .01$

MAIN EFFECT MEANS AND STANDARD DEVIATIONS

SCENE

	Runway	Grnd-to-Air	Approach
MEAN	37.19	35.94	48.13
S. D.	48.41	48.06	50.04

JOINT WIDTH

	.125°	.25°	.50°	1.0°	2.0°
MEAN	67.71	38.54	37.50	26.04	32.29
S. D.	46.88	48.80	48.54	44.00	46.88

DISPLACEMENT

	4.7"	14.1"	42.3"	84.6"
MEAN	49.17	35.00	36.25	41.25
S. D.	50.10	47.80	48.17	49.33

" = Arc Seconds

Table 2. ANOVA Summary for Percent "Aligned" Responses to Scene Displacement in the Display Joints Study

ANOVA TABLE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM /n-1	MEAN SQUARES	F
SCENE	81770.83	2/30	40885.42	F = 12.75**
JOINT WIDTH	76416.67	4/60	19104.17	F = 8.89**
S x J	136458.33	8/120	17057.29	F = 10.12**
DISPLACEMENT	12750.00	3/45	4250.00	F = 3.09*
S x D	70562.50	6/90	11760.42	F = 6.27**
J x D	67666.67	12/180	5638.89	F = 3.57**
S x J x D	183708.33	24/360	7654.51	F = 4.30**
PILOTS	159833.33	15		
S x P	96229.17	30	3207.64	
J x P	128916.67	60	2148.61	
S x J x P	202208.33	120	1685.07	
D x P	61916.67	45	1375.93	
S x D x P	168770.83	90	1875.23	
J x D x P	284333.33	180	1579.63	
S x J x D x P	640291.67	360	1778.59	
TOTAL	2371833.33	959		

* $P < .05$
** $P < .01$

MAIN EFFECT MEANS AND STANDARD DEVIATIONS

SCENE

	Runway	Grnd-to-Air	Approach
MEAN	50.31	51.88	31.56
S. D.	50.08	50.04	46.55

JOINT WIDTH

	.125°	.25°	.50°	1.0°	2.0°
MEAN	28.13	45.83	45.83	55.21	47.92
S. D.	45.08	49.96	49.96	49.86	50.09

DISPLACEMENT

	4.7"	14.1"	42.3"	84.6"
MEAN	39.58	49.58	45.83	43.33
S. D.	49.01	50.10	49.93	49.66

" = Arc Seconds

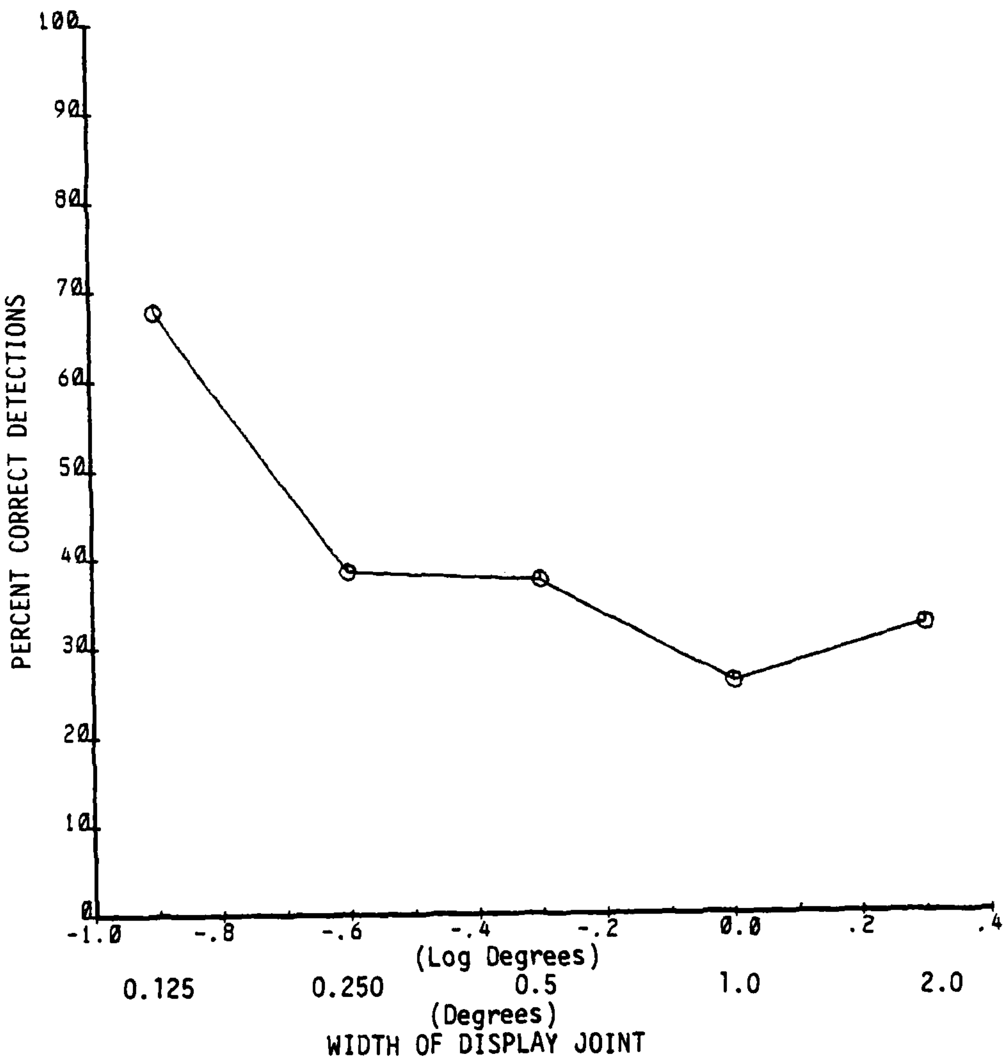

Figure 5. Visual discrimination of vertical displacement of the left channel as a function of joint width (data collapsed across seenes and displacements).

other larger separations. The separations from .25° to 2° are probably not significantly different from each other.

A graphic determination of the 50-percent threshold is at .19° of joint width. Joints wider than this would mask displacements up to 1.4° arc minutes, and their discrimination would occur less than 50 percent of the time. Joints separating two channels whose width is less than .19° would allow discrimination of the same displacements more than 50 percent of the time.

Turning to the analysis on percent of aligned responses, Figure 6 provides similar data for a 0.125° joint width. The probability of aligned responses is less than 30 percent, whereas for joints of greater width, the probability is approximately 50 percent.

Magnitude of Displacement

Theoretically, the greater the magnitude of displacement, the easier the discrimination of misalignment and the greater the number of correct responses. No such direct function was obtained as can be seen in Figure 7. The four displacement magnitudes chosen for this study began with a value near 5 arc seconds. We increased this value by three times. We tripled this value for the next two steps and then doubled it for the last step.

The fractional values for displacement given in Tables 1 and 2 are a product of the Mann Comparator's being calibrated in 0.001 millimeter increments. In taking and producing the photographs, a physical displacement of 0.003 millimeter resulted in a displaced misalignment of 4.7 arc seconds. The 4.7 arc second initial point was chosen to be inside 7 arc seconds, a value obtained by Berry (1948), who found that with some degree of separation, this level of vernier acuity could be discriminated by most people.

A possible explanation for the shape of the function obtained in Figure 7 would be that the magnitude of the displacements used is masked by the width of the joints. This does not necessarily appear to be the only explanation. Figure 8 indicates an interaction between the magnitude of the displacement and the width of the joint in the display. The displacements of 4.7 and 14 arc seconds have similar functions. Also a common function applies for the displacements of 42 and 85 arc seconds. The curious factor here is that these two pairs are in an inverted order. Higher performance in terms of the detections is found for the displacement magnitudes of the two lesser amounts at display joint widths of .25°. For all display joint widths greater than .25°, there are no percent correct averages that exceed 50 percent.

The upturn percentage number of correct detections observed in Figure 8 is contributed by three out of the four magnitudes of displacement. The interaction with the three scenes may assist in explaining these data. Reference to Figure 9 illustrates that the approach scene

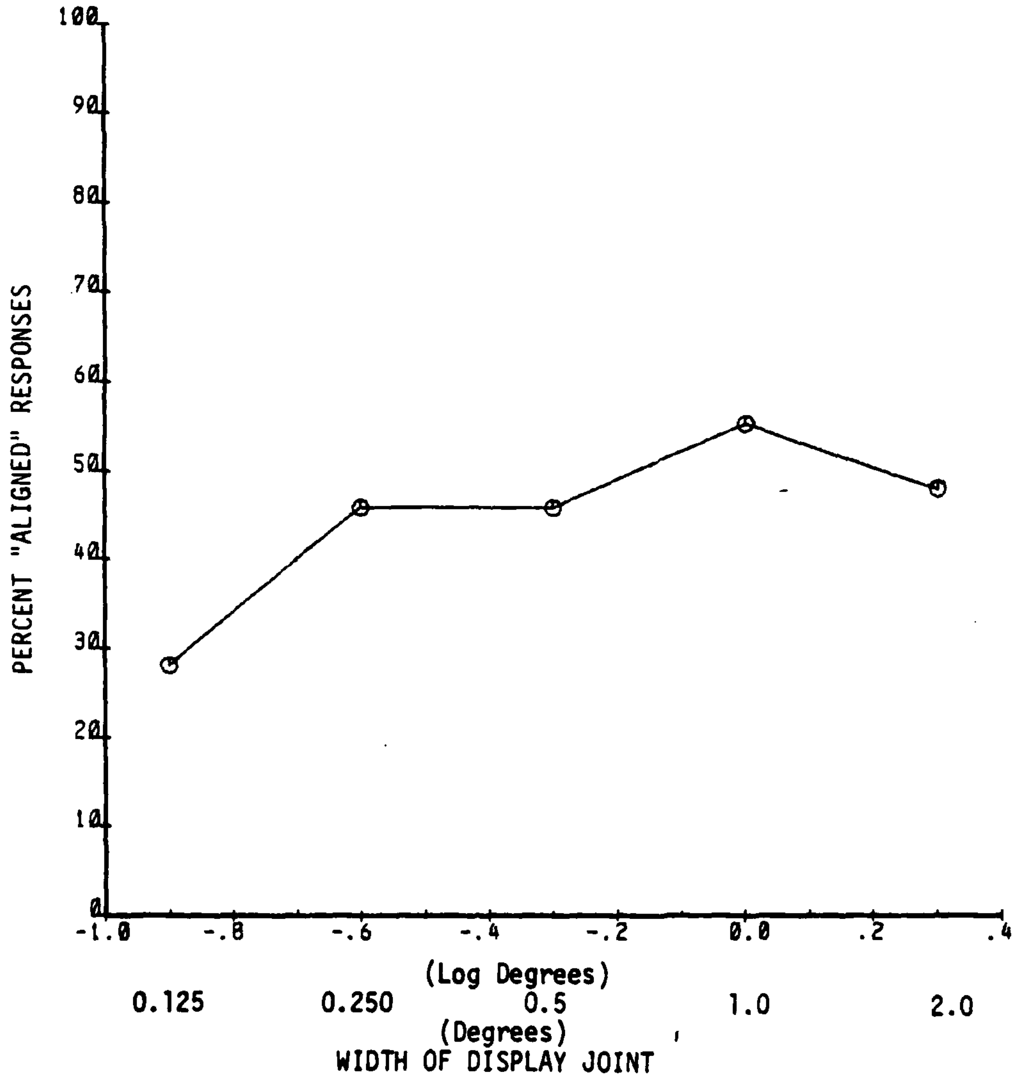

Figure 6. "Aligned" responses made to vertical displacements of the left channel as a function of joint width (data collapsed across scenes and displacements).

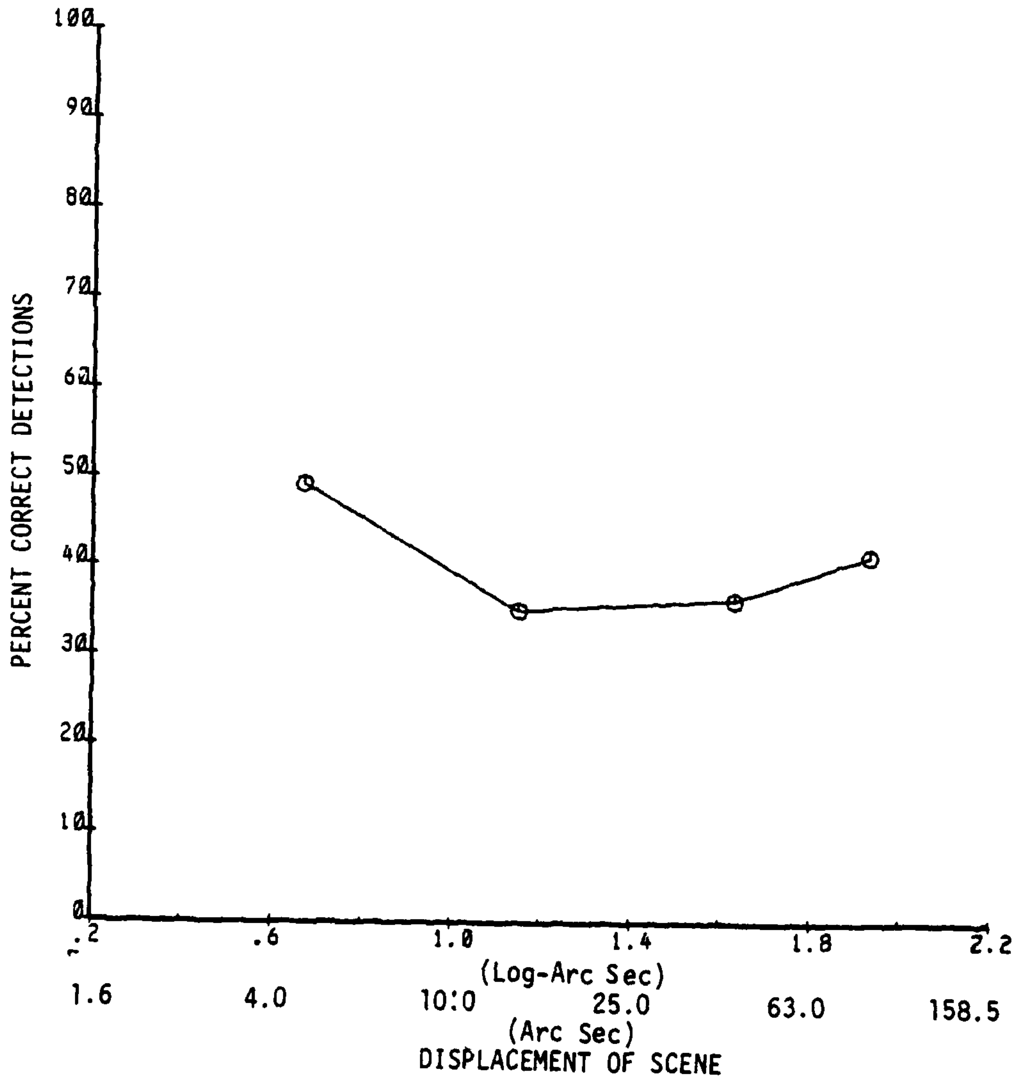

Figure 7. Visual discriminations of vertical displacement of left channel as a function of magnitude of displacement.

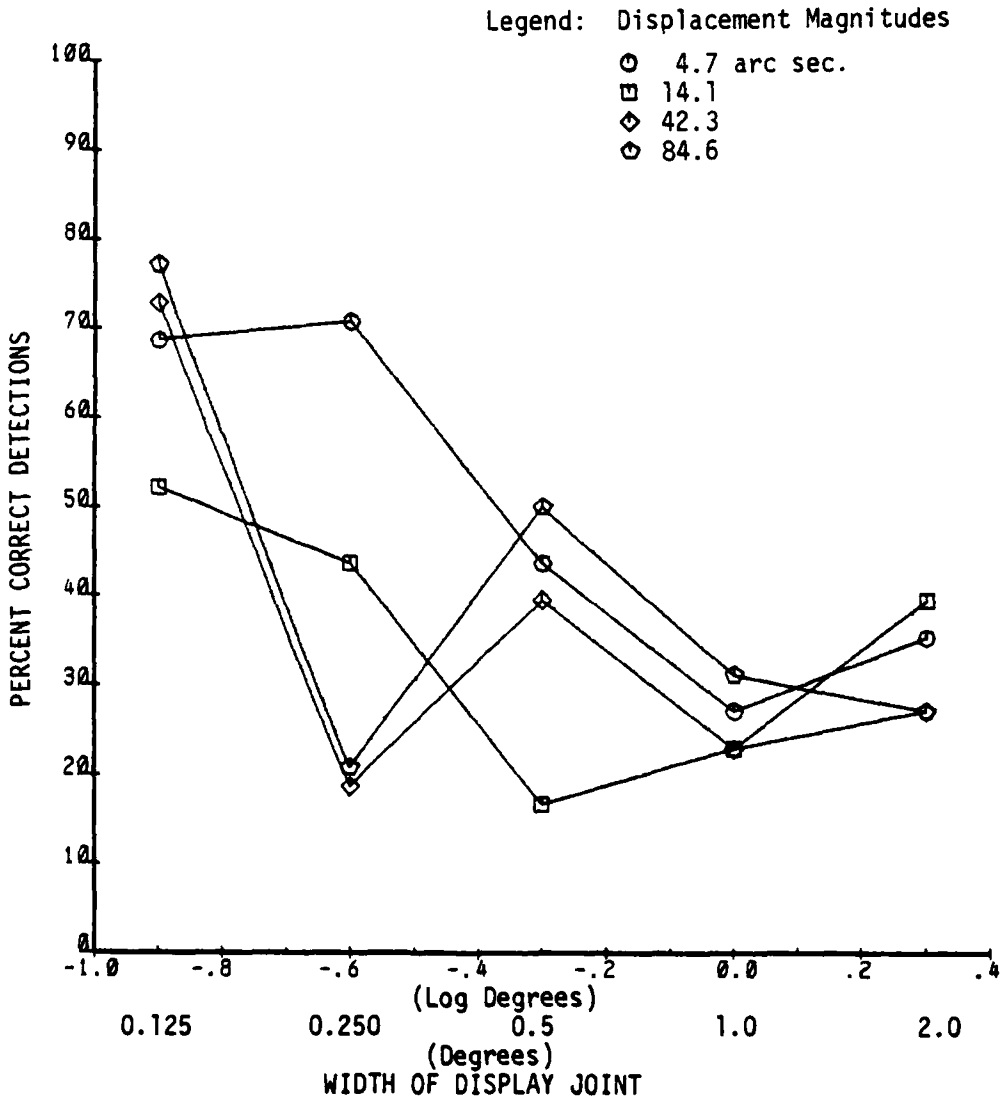

Figure 8. Visual discrimination of vertical displacement of the left channel as a function of the interaction between displacement magnitude and joint width.

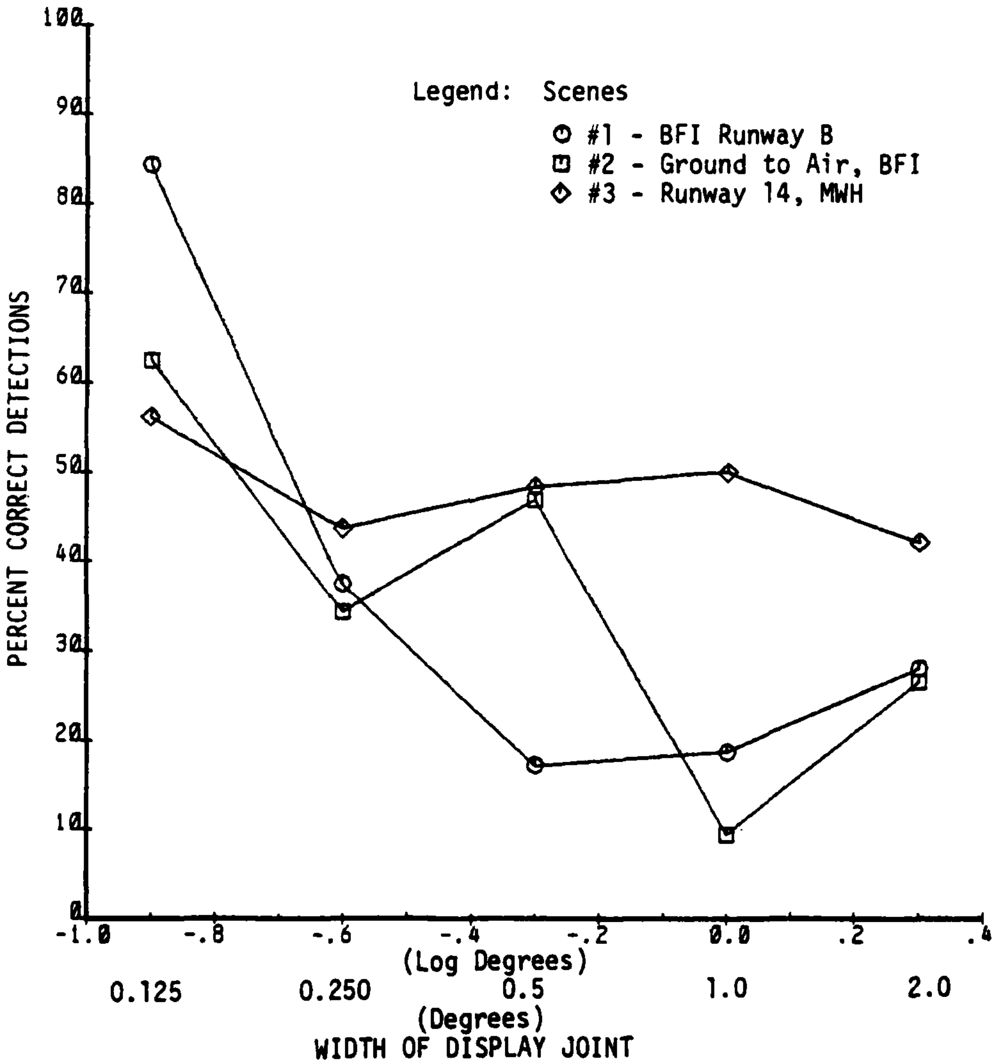

Figure 9. Visual discrimination of vertical displacement of the left channel as a function of the interaction between CGI scene and joint width.

is least affected by the change in the width of the joints, whereas scenes 1 and 2 have somewhat similar functions, decreasing as joint widths increase, until 1° of separation is reached. A joint width of 2° shows an increased performance in the number of correct detections for both scenes.

As in most transport aircraft, these stimuli used a vertical divider between the two channels. This vertical septum forms part of a well known illusion, the Poggendorff illusion. If a line in the scene behind that septum forms an oblique that passes through that septum, entering and reappearing portions of the oblique, which are part of a continuous line, will not appear to be in a straight line. For instance, if the line begins in the upper right and goes behind a vertical septum, it appears to emerge with a downward displacement on the left. In scene 1, the Boeing Field International (BFI) runway is depicted in such a location that the left edge line of the runway passes behind the septum in just this fashion. In choosing the direction for the displacement for the left channel, we reasoned that an upward displacement would be atypical because with such a displacement the horizon line would appear to break. If the displacement were downward, it might be interpreted as normal curvature of the horizon. Therefore, it was reasoned that the more critical threshold would be the upward displacement of the left channel image. This direction of displacement may, however, be countered by the Poggendorff illusion in these specific scenes. For each of the magnitudes of displacement upward, there may be an opposite perceptual effect by the presence of the septum and by the fact that the Poggendorff illusion increases with the width of the septum, at least within the range of these joint widths.

In Figure 9, the observation of the changes in the number of correct detections for scene 1 appears to have this combination of influences. As the septum width increases from .125° to .25° to .5°, there is a systematic decrease in the number of correct responses. Then, there is an upturn between joint widths of 1° and 2°. Scene 2, on the other hand, has no diagonal lines going through the septum. The shade banding in the sky is almost perpendicular to the vertical septum, and the Poggendorff illusion does not pertain to perpendicular lines. Scene 3 has a diagonal line between two fields that passes obliquely through the septum. Therefore, it was anticipated that scene 3 would show a Poggendorff effect similar to that in scene 1. The only exception would be the case of the widest joint, for in this instance, the joint covers the tip of the diagonal line. However, the diagonal line in scene 3 extends but little beyond the septum, and with the wider joint widths, the end of the line is not seen at all. Furthermore, the horizontal lines in the scene are much more prominent than is the single diagonal. In other words, in specific instances a Poggendorff effect can be offset by judgments based on vernier acuity in responding to the alignment of two halves of a scene.

The Poggendorff Illusion

The Poggendorff illusion is the strongest in a class consisting of shape and direction illusions. This group predominantly includes distortions in apparent shape, parallelism, and collinearity which seem to arise in patterns with numerous intersecting line elements. The underlying mechanism is presumably structural in nature, probably involving optical aberrations and lateral inhibitory influences. The Poggendorff has its maximum influence when the septum is vertical. Orientation of the whole illusion stimulus is also important in terms of magnitude of the effect. Green and Hoyle (1964) show that when the oblique is horizontal, the illusion is reduced, and Leibowitz and Toffey (1966) confirmed this in more detail. They used a Poggendorf figure with a 45° oblique and displayed it in four orientations: parallels vertical, parallels horizontal, and parallels tilted to the left and right at 45°. The effect with the parallels (like the joint), vertical or horizontal, was double that with the parallels at 45°. This result is identical to that of Obonai, as reported by Robinson, 1972. The distortion is more marked when the judged line is at 45° than when it is vertical or horizontal. This agrees well with the data on the Zollner illusion. That illusion is maximal in the 45° version when the judged lines are at 45° as found by Judd and Courten (1905).

In both these illusions, there appears to be something about the vertical and horizontal orientation which acts against the distorting effect. Adaptation level theorists Helson (1964), and Green and Hoyle (1964) have suggested that we perceive orientations more accurately when they parallel these spatial norms. Certainly if this aspect of the perceptual system is based on orientation-specific neural units, then it may be something that we have to deal with in the simulation of the real world by CGIs which are primarily made up of edges or lines.

There are few reported studies of the effect of varying the angle of the oblique in the standard Poggendorff figure. In such a study, the judgment can be carried out either by adjusting one of the sections of the oblique by displacing it without altering its orientation, or by adjusting it simply by rotating it about its junction with the parallel. Using the former method, Cameron and Steele (1905) reported increasing apparent displacements of the sections of the oblique with decreasing angle of the oblique. Wagner (1969) used the same method but then derived the apparent angular distortion from his results by means of a mathematical expression. Wagner's displacement measures were very similar to those of Cameron and Steele, a steadily increasing displacement with decreasing angle. When converted to angular distortions however, Wagner's data are more like some of the data from other figures involving angular distortion such as the Zollner. They show a rise from 10° to a maximum of 30° and then fall to 45°.

In their extensive studies of the Poggendorff illusion, Tong and Weintrub (1974) included variation in the width between the parallels. The parallels are like the left and right hand edges of our "joints" between displays. Their "inverted" Poggendorff is closest to our application. Converting their experiment VII data into the equivalent perceived downward angular displacement in this experiments display, the perceptual modification of our displacements is shown in Table 3.

Table 3
Theoretical Modification of Displacement Variable Imposed by the Poggendorff Illusion

Physical Displacement in Stimuli, Degrees	Equivalent Perceived Displacements as Modified by the Poggendorff Illusion for Each Width of "Joint"				
	.125°	.250°	.50°	1.0°	2.0°
.08	.07	.03	-.03	-.16	-.53
.23	.22	.18	.12	-.01	-.38
.70	.69	.65	.59	.46	.09
1.40	1.39	1.35	1.29	1.16	.79

Value = downward perceptional displacement
+ Value = upward perceptional displacement

The effect of the Poggendorff illusion increases with the width of the joint and could account for the lower frequency of correct responses as the joint width was increased. Therefore, it appears reasonable that the angular width of the display septum does influence discrimination of vertical displacement and that the specific values obtained in this experimental study are the result of the interactions between the influence of the Poggendorff illusion and the scenes used in the study, the magnitudes of displacement, and the joint widths. A more extensive study would be necessary to establish more reliable values for each width of septum under all conditions.

In more than 22 percent of the presentations displacements of up to 12 times the vernier acuity threshold (7 arc seconds at 15 arc minutes of separation Berry, 1948) are not perceived as displaced. This phenomenon involves the counteraction of the Poggendorff illusion. A second hypothesis is that the patterns in the complex scene make the vernier discriminations more difficult than in the laboratory displays of high contrast targets against a homogeneous background. Whatever the case, these data do not provide us with a definitive and non-c[illegible]ed answer as to the basis for the shape of the function between separations of 0.125° and 2°. The larger separations found in operational simulators (2° to 20°) were not included in this investigation, because it appeared that this was not a range of separation of high interest. It seems logical to assume that the wider septums of this range will probably have less effect in terms of such things as the Poggendorff illusion and also that the larger angular separations will likely decrease the discrimination of small differences in displacement.

CONCLUSIONS AND RECOMMENDATIONS: DISPLACEMENT

Given the limitations stated in the introduction, a separation of approximately .2° between adjacent channels of a composite CIG display should be adequate to reduce the probability of the detection of vertical displacements between two channels of up to 1.4 foot of visual angle. This specification is for the "worst case" perceptual situation in which the separation or joint is oriented vertically.

It can be expected that for those scene conditions where strong oblique lines cut through the joint at angles approaching between 10° to 80°, the probability of detecting misalignment will rise and in other conditions fall due to the presence of conditions which produce the Poggendorff illusion. An example of such a case is the horizon during banks. If the slope of the horizon is in the same direction as the misalignment, the probability of detecting the alignment error will increase. If the slope is in the direction opposite the misalignment, the probability of detection will decrease. (Consideration of such cases in establishing specification or design limits must be further qualified by the fact that perfectly aligned channels will exhibit a perception of misalignment for sloping lines and that this perception will become stronger as the gap width increases up to 2°.)

RESULTS AND DISCUSSION: ROTATION

Misalignment of Scenes

The center of rotation of the left channel portion of the scene was centered both vertically and horizontally in the joint. This type of misalignment was a pure angular misalignment only at this point of rotation. Above and below this center, the displacement has a vernier displacement component as well as an angular misalignment. Near the top of the display, say at the radius of 13.5° from the center of rotation, a horizontal line in the scene will have both a step function and an angular deviation from horizontal. Therefore the pilot can look for two major cues at the top and bottom of the scene: displacement and angular deviation.

The angular rotations imposed in the stimuli were 0.0, 0.5, 1.0, and 2.0 degrees. There were five joint widths and they were identical with those used in the displacement study: 0.125, 0.25, 0.50, 1.0 and 2.0 degrees. The scenes were also duplicated: scene 1 - on the end of the BFI runway, scene 2 - a ground-to-air scene of an airborne transport, and scene 3 - a backcourse approach to runway 14 MWH. These were the main effects in the two ANOVAS completed, one each with the dependent measures of percent correct detections and percent "aligned" responses.

For the category of correct detections, all main effects and two of the first-order interactions proved to be statistically significant at the probability level of .05 or .01. The interactions of scenes with joint width and scenes with rotations were significant. The interactions of joint width and rotation, as well as scene, joint width, and rotation as a second order interaction, were not significant (See Table 4.)

For the "aligned" responses, the two main effects of scenes and joint width, and their interaction, were not significant. However rotations and all interactions with rotation were significant a $p =< .05$ (shown in Table 5).

Table 4. ANOVA Summary for Percent Correct Detections of Rotational Misalignment in the Display Joints Study

ANOVA TABLE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM /n-1	MEAN SQUARES	F
SCENE	44333.33	2/30	22166.67	F = 6.92**
JOINT WIDTH	17833.33	4/60	4458.33	F = 3.12*
S x J	34000.00	8/120	4250.00	F = 2.92**
ROTATION	422333.33	2/30	211166.67	F = 166.22**
S x R	28333.33	4/60	7083.33	F = 3.96**
J x R	16416.67	8/120	2052.08	F = 1.09
S x J x R	20000.00	16/240	1250.00	F = 0.99
PILOTS	127055.56	15		
S x P	96111.11	30	3203.70	
J x P	85722.22	60	1428.70	
S x J x P	174444.44	120	1453.70	
R x P	38111.11	30	1270.37	
S x R x P	107222.22	60	1787.04	
J x R x P	225361.11	120	1878.01	
S x J x R x P	302222.22	240	1259.26	
TOTAL	1739500.00	719		

* $p < .05$
** $p < .01$

MAIN EFFECT MEANS AND STANDARD DEVIATIONS

SCENE

	Runway	Grnd-to-Air	Approach
MEAN	55.83	70.00	51.67
S. D.	49.76	45.92	50.08

JOINT WIDTH

	.125°	.25°	.50°	1.0°	2.0°
MEAN	54.86	54.86	56.25	62.50	67.36
S. D.	49.94	49.94	49.78	48.58	47.05

ROTATION

	.50°	1.0°	2.0°
MEAN	30.83	56.67	90.00
S. D.	46.28	49.66	30.06

Table 5. ANOVA Summary for Percent "Aligned" Responses to Rotational Misalignment in the Display Joints Study

ANOVA TABLE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM /n-1	MEAN SQUARES	F
SCENE	7750.00	2/30	3875.00	F = 1.71
JOINT WIDTH	8395.83	4/60	2098.96	F = 1.19
S x J	25791.67	8/120	3223.96	F = 2.00
ROTATION	344458.33	3/45	114819.44	F = 57.07**
S x R	85416.67	6/90	14236.11	F = 8.80**
J x R	32937.50	12/180	2744.79	F = 1.90*
S x J x R	109375.00	24/360	4557.29	F = 3.80**
PILOTS	81958.33	15		
S x P	67916.67	30	2263.89	
J x P	106270.83	60	1771.18	
S x J x P	193541.67	120	1612.85	
R x P	90541.67	45	2012.04	
S x R x P	145583.33	90	1617.59	
J x R x P	260395.83	180	1446.64	
S x J x R x P	431291.67	360	1198.03	
TOTAL	1991625.00	959		

* $P < .05$
** $P < .01$

MAIN EFFECT MEANS AND STANDARD DEVIATIONS

SCENE

	Runway	Grnd-to-Air	Approach
MEAN	30.00	25.63	32.50
S. D.	45.90	43.72	46.91

JOINT WIDTH

	.125°	.25°	.50°	1.0°	2.0°
MEAN	26.56	29.17	29.17	34.90	27.08
S. D.	44.28	45.57	45.57	47.79	44.56

ROTATION

	0°	.50°	1.0°	2.0°
MEAN	53.75	38.75	22.08	2.92
S. D.	49.96	48.82	41.57	16.86

Rotation as a Main Effect

As a main effect, rotation was significant in the ANOVA for both response measures. The magnitude of the effect can be seen in Figure 10 for the percent of correct detections. The reverse function with a downward shift is found for the "aligned" responses in Figure 11. In this Figure, note that the zero rotation cases also are included.

Rotation values of 0.5, 1.0 and 2.0 degrees were selected after a preliminary investigation. Two 8 x 10 inch achromatic prints of the approach to runway 23 at Moses Lake (MWH) were cut to simulate both the forward and left forward oblique channels. A pin was inserted so that the left forward oblique photograph could be rotated around the center of the edge of the forward scene. A piece of chart tape 1/8-inch wide simulated the gap. Eleven individuals were asked to make five settings (without feedback) such that the pictures looked aligned. The range of the 11 means was .03° to 1.49°, and the standard deviation of these means was 49.6 arc minutes, or 0.83°. The maximum rotation value was set at 2.5 times the standard deviation or 2°, a value that would include 99 percent of the population. One-half of this value was used for the intermediate rotation (1°), and one-fourth for the smallest rotation of 0.5°.

In both ANOVAs, rotation gave very large F ratios, and Figure 12 shows that for each of the five joint widths, the three rotations were easily discriminated. The shapes of the function of percent correct responses versus rotation of the scene for different joint widths are common and range from 18 to 92 percent. The step intervals for rotation provided an ideal range of percent correct detections and are indicative of a sensitive measure.

Rotations of 2° are easily discriminated (82 to 92 percent correct) for all joint widths. The three narrower joint widths, (0.125°, 0.25°, and 0.5°) appear to mask the 0.5° rotation more than the two wider joints of 1.0° and 2.0°. When the joint widths are the narrower angles of 0.125°, 0.25° and 0.5°, responses to the smaller rotation (0.5°) are less frequently correct. Greater attenuation of perception by the wider joints may have led to more frequent guessing that a rotation existed in scenes with the 1.0° and 2.0° joint widths when the rotation of the images was actually small (0.5°). Figure 12 illustrates that such guessing might have led to the greater frequency of correct responses for the two widest joints. Statistically, this greater frequency could be due to chance. Figure 13 illustrates an interaction that is statistically significant. The frequency of aligned responses is significantly higher for two joint widths, 0.5° and 1.0°, for the two rotations of 0.0° and 0.5°. The relatively easy discrimination of the 2° and 1° rotations may have imposed the equal frequency of aligned responses across all joint widths, and this may have changed the shape of these specific functions in contrast with those for the 0.0° and 0.5° rotations.

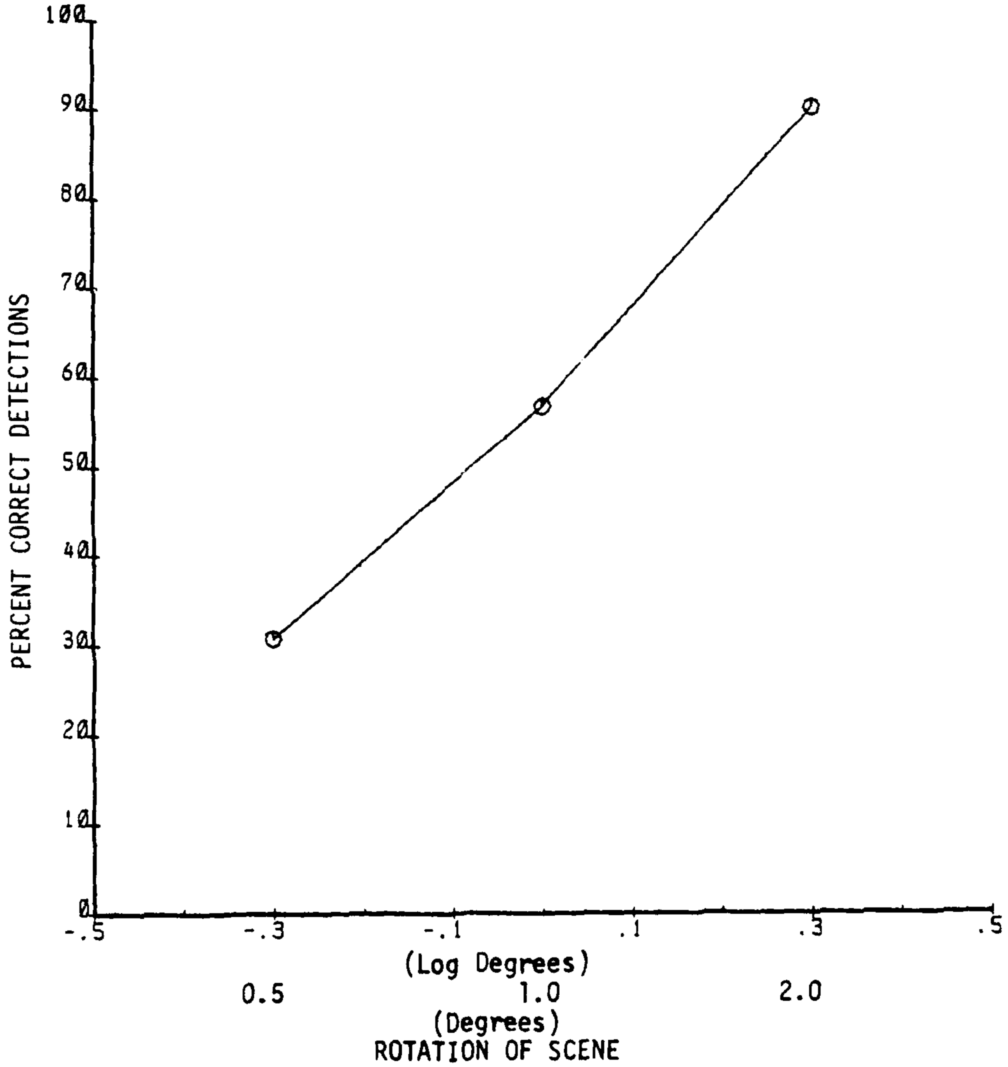

Figure 10. Correct responses as a function of rotation of the scenes.

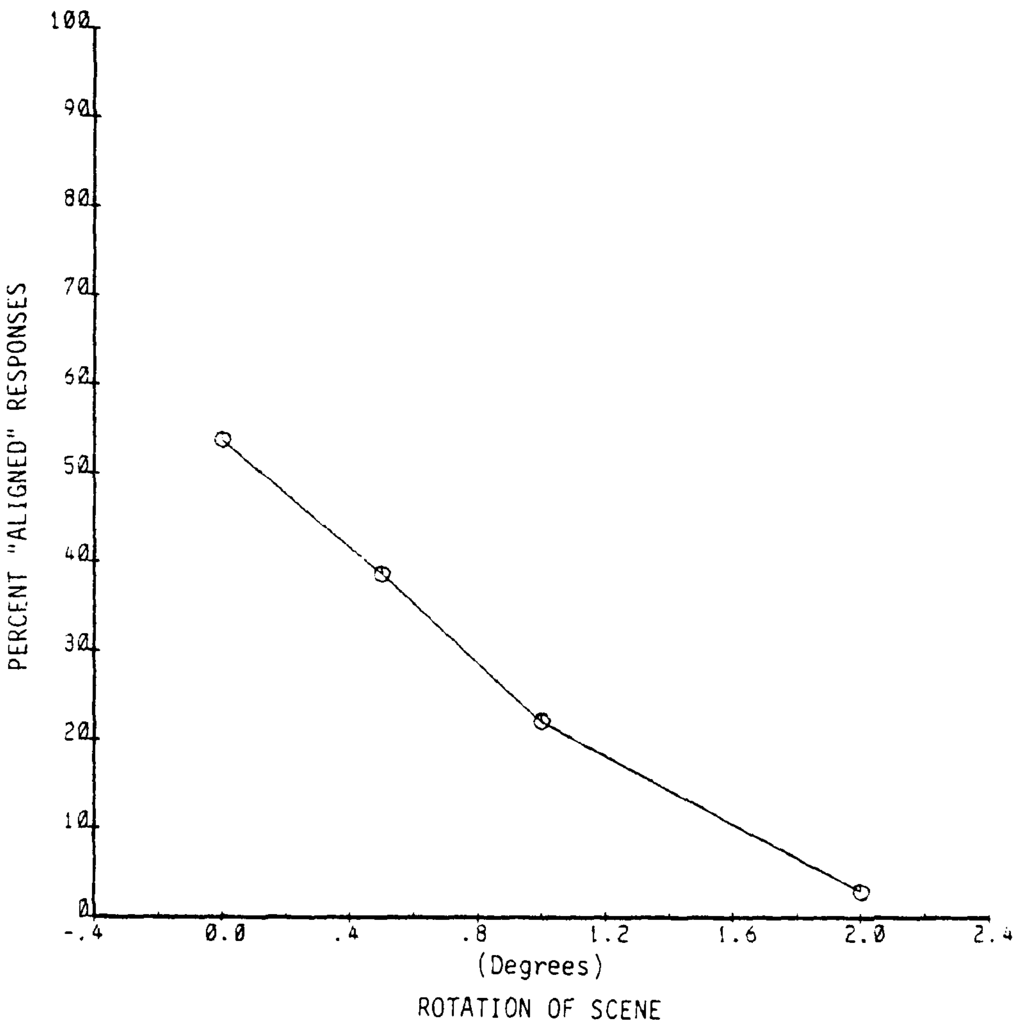

Figure 11. Aligned responses as a function of rotation of the scenes.

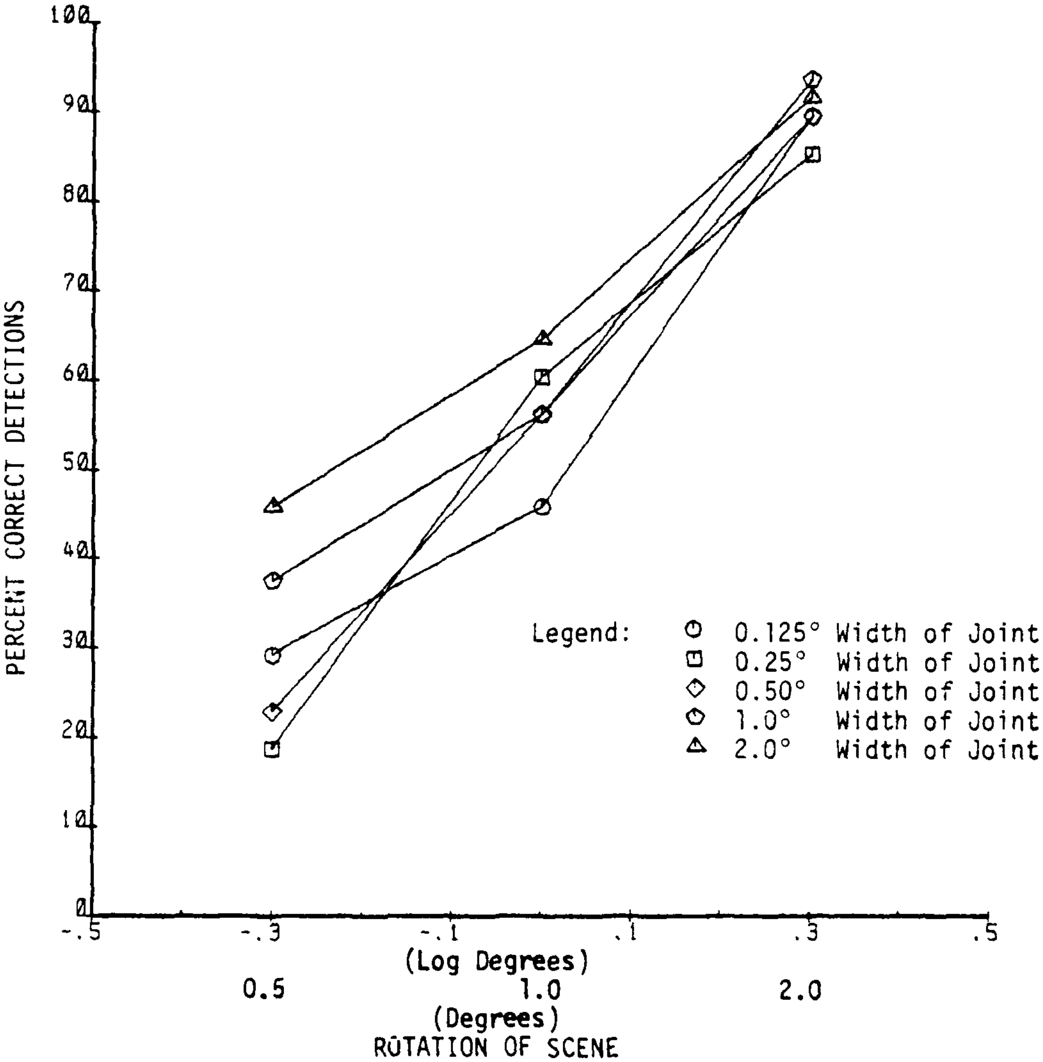

Figure 12. Percent correct responses for each joint width as a function of rotation of the scene.

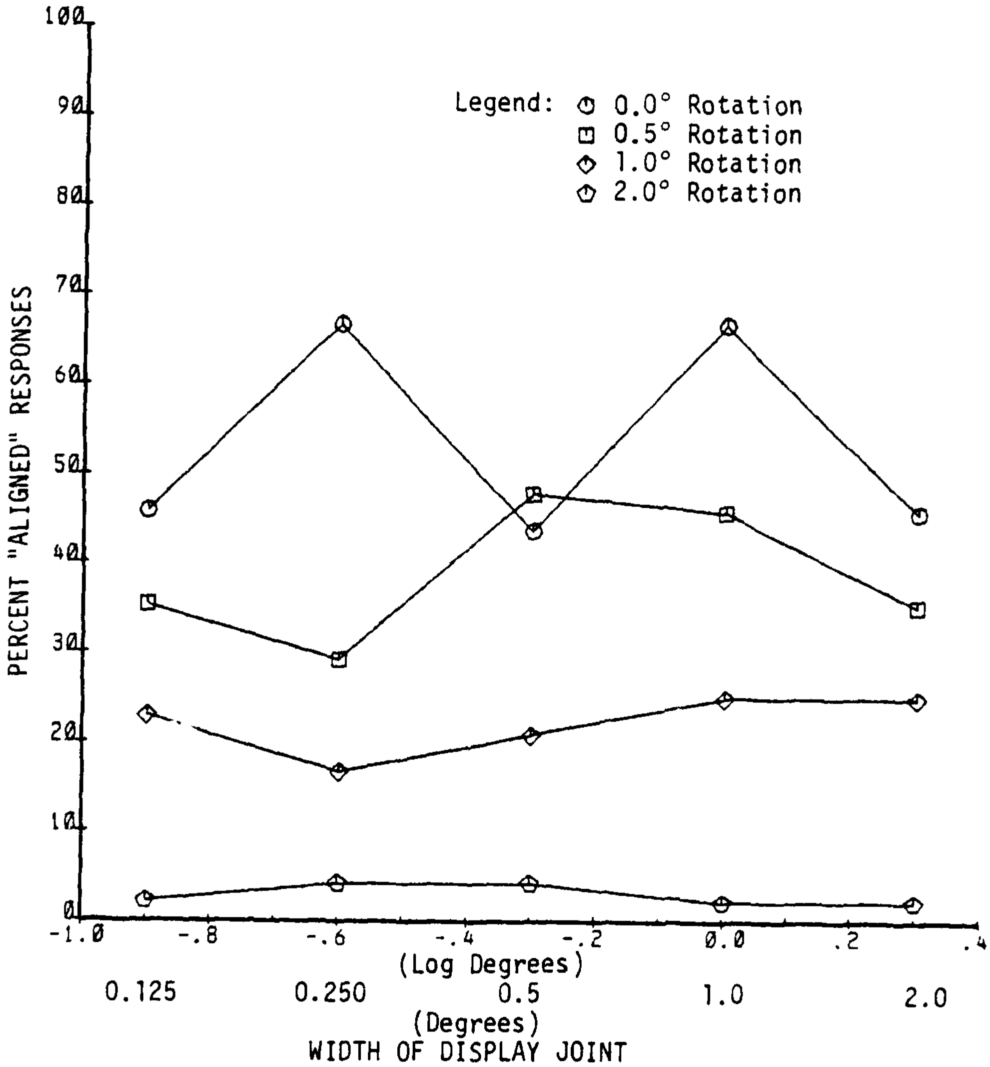

Figure 13. Aligned responses for each rotation as a function of joint width.

Joint Width and Rotation

The influence of display joint width on the percent correct discriminations, when the data are collapsed across scenes and rotations, is shown in Figure 14. The influence of the joint widths of the three smallest sizes is of a common magnitude, about 55 percent. For the two larger joint widths, 1° and 2°, the influence is to increase the proportion of correct detections, indicating that as the width of the joint increases, there is somewhat better discrimination of the rotation. This is an unexpected finding.

In Table 4, the ANOVA indicates that joint width is significant although the increase in percent correct detections above 0.5° joint width is only about 10 percent. The reader should note that the influence of joint width on rotation discrimination is opposite that for the discrimination of displacement. As the joint width increases, the discrimination of displacement decreases while the discrimination of rotation increases. A potential explanation is that with the joint widths used, the discrimination of a rotation may be perceived and classified by the pilot as a displacement. Figure 15 indicates that there is no equivalent decrease in the number of aligned responses for the widest joint widths.

Figure 16 shows the relative influence of joint width on the effect of the three different amounts of rotation on correct detections. A change in the discrimination of rotation as a function of the joint width is apparent but not consistent with the two smaller rotations (.5° and 1°). The trend is that the wider the joint, the greater the discrimination of the rotation. However, the two degree rotation condition is not affected by joint width, since 90 percent or more of these rotations are discriminated with all joint widths. In other words, a 2° rotation is so easily discriminated that there are no degrees of freedom left to reflect the influence of joint width. The influence of the three narrowest joint widths on the two smaller rotations explains why Figure 15 shows a nearly constant influence for joints of .125° to .5°. The variations between these two different rotations tend to balance each other.

Joint Widths by Rotation by Scenes

Figure 17 shows that Scenes 1 and 3 are discriminated about similarly for all joint widths and Scene 2 shows an increase in discrimination for joint widths .5°, 1°, and 2°. Scenes 1 and 3 are air-to-ground views and scene 2 is a ground-to-air view. Therefore it would be logical to expect that, with a "clear air" background, the discrimination of rotation would be more difficult and that, under such circumstances the width of the display joint would, if anything, decrease the discrimination.

In scene 2 however, the sky is a series of blue shades of differing luminous intensity, or shade banding that runs horizontally across the scene. These are not distinct lines, but have the general appearance of Mach bands. These bands may be good discrimination cues, particularly

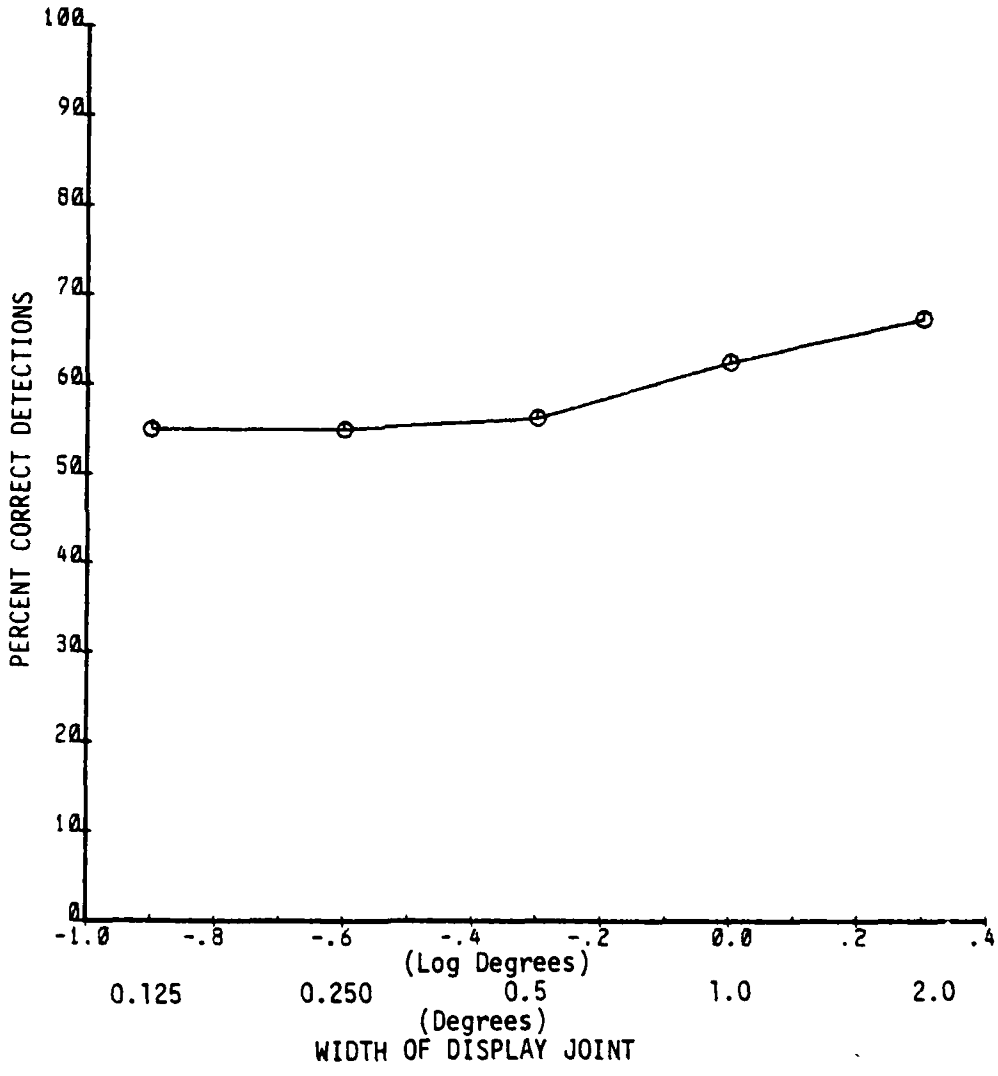

Figure 14. Correct responses for rotational misalignments as a function of joint width.

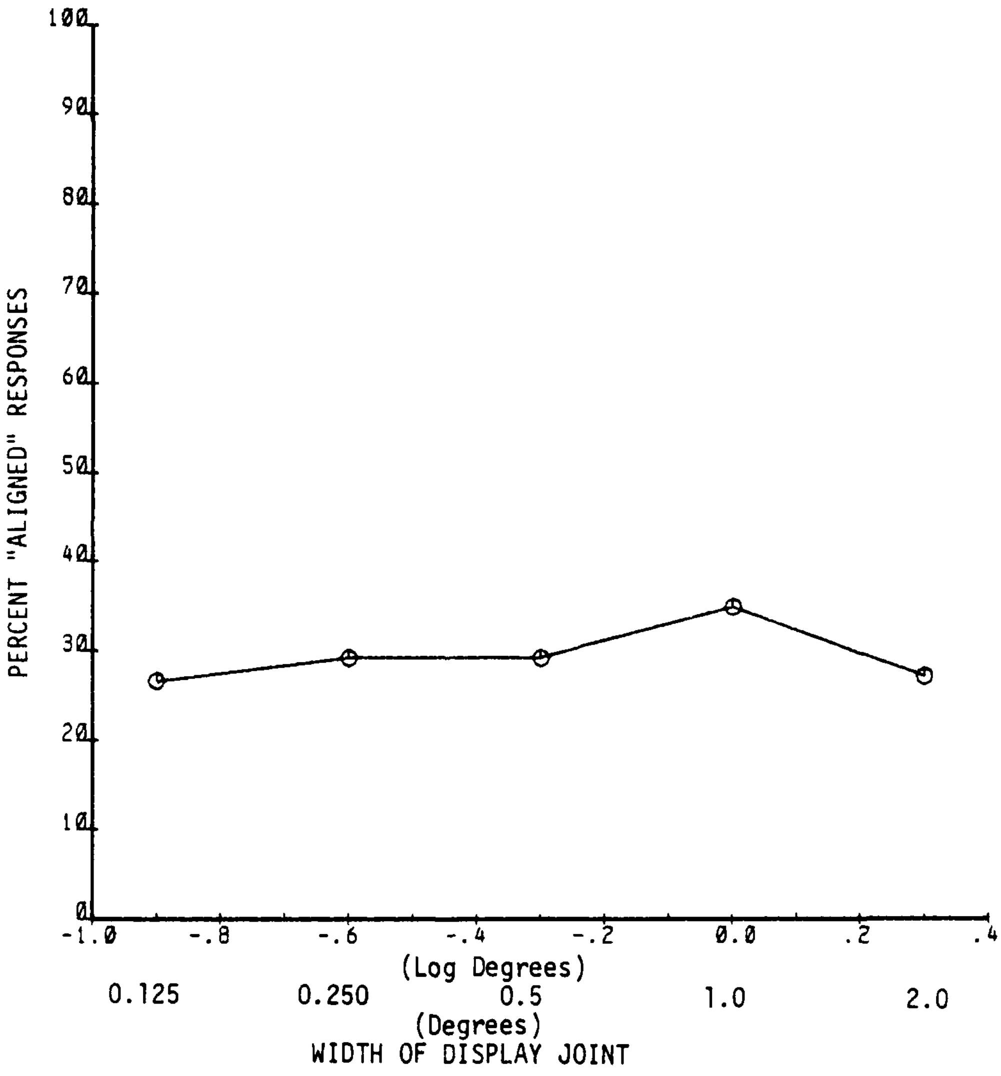

Figure 15. Aligned responses for rotational misalignments.

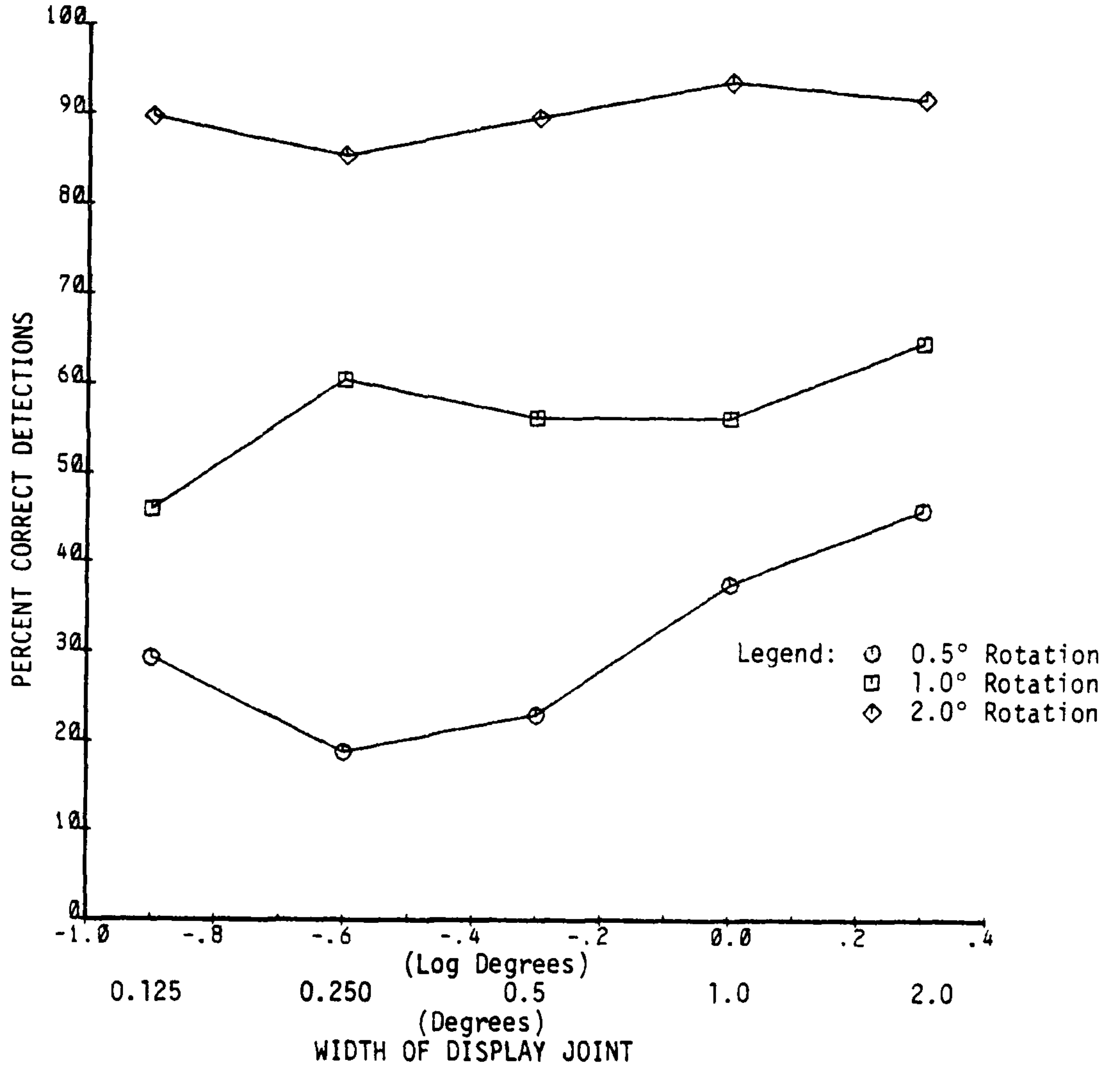

Figure 16. Correct responses for rotational misalignments as a function of magnitude of rotation and joint width.

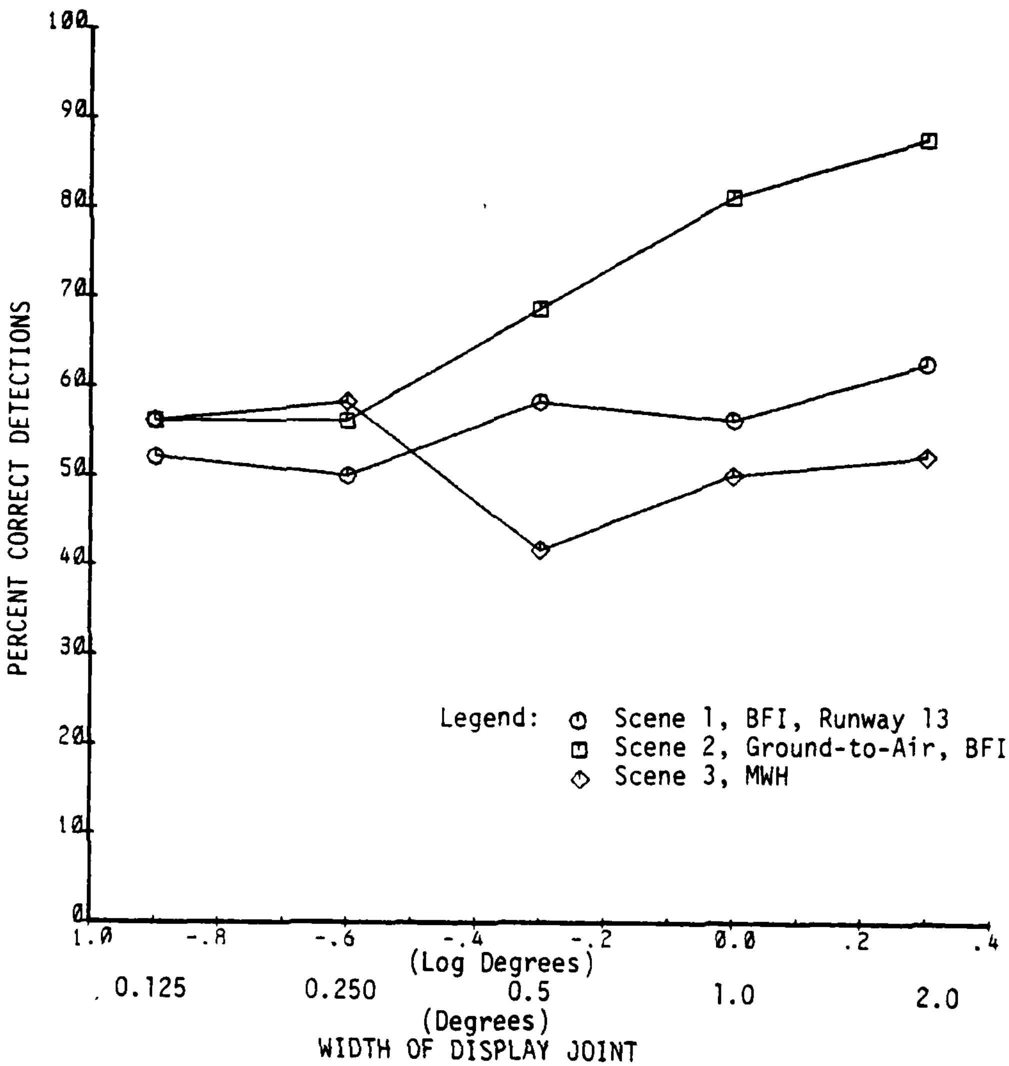

Figure 17. Correct responses for rotational misalignments as a function of scenes and joint width.

for rotation, and the width of the septum may assist in discrimination of the differences in slope of distinctly separated segments of the same band.

It appears from examination of Figure 17 that scene 2 was the major contributor to the increased probability of detecting of rotation for the larger gap widths. Complexity, as a dimension, was not scaled. However if these three scenes were to be quantified in terms of frequency of lines or objects, the order would be 1, 3 and 2. In the interaction among joint widths and scenes, the rotational errors were most easily discriminated in the simplest scene. The specifics of the horizontal shade banding in the sky, providing relatively wide stripes for the discrimination of rotational errors, appeared to be the untested explanation for these data.

Conclusions and Recommendations: Rotation Study

For the conditions of this study, it was found that rotations of up to 1° between adjacent channels were not detectable at the 50 percent level for a gap width of .125°, and that rotations of 0.5° were detected less than 50 percent of the time for all gap widths studies. The gap widths larger than 0.125° proved to be less effective in suppressing the detection of rotation of one channel relative to the other than were the smallest tested (0.125°). This was an unexpected finding, and examination of the results showed that the effect was strongly scene dependent. Though not tested, it is hypothesized that this effect was due to the presence of strong horizontal bands in the scene which demonstrated the effect most clearly.

In was not possible to determine the effect of smaller gap widths from the data in this study, but in this regard, two factors are especially important:

1. The 0.125° value represents the state of the art in juxtapositioning channels in present large screen CIG systems.

2. The experimental literature on vernier acuity suggests that closer spacing will result in an increased probability of detecting displacements.

STUDY I: SUMMARY

The purpose of this study was to determine the effect of the width of the gap between two adjacent CGI channels on the perception of relative errors between the two in vertical and rotational alignment, with the goal of deriving data which are useful in providing guidance in the specification and design of multi-channel visual scene generation systems. In applying these data, it is necessary to carefully contrast the conditions used in this study with those of the planned application. In review, the study conditions were as follows:

1. All three scenes represented daylight conditions.

2. The operational CIG imagery was based on 1980 state of the art.

3. Static rather than dynamic scenes were used.

4. The experimental design permitted study of a larger range of conditions at the expense of sensitivity of the detection differences among the conditions.

5. All subjects were experienced Air Force MAC pilots.

The data indicated the following:

1. For worst-case conditions, separations between adjacent channels of about .2° are adequate to reduce below the 50 percent level of probability the detection of vertical misalignments of up to 1.4 minute of visual angle. The use of wider separations must be approached with caution since diagonal lines in the scene, whether due to the geometry of the scene or to aircraft maneuvering, may act to increase the perception of misalignment through the operation of a phenomenon known as the Poggendorff illusion.

2. The probability of detection of differential rotations of up to 1° between adjacent channels is below 50 percent for gap widths of .125° of visual angle. As was the case with the perception of vertical displacements, the study showed that increasing the gap width increased the probability of the detection of misalignment. This latter finding appeared to be scene dependent, and the effect was largest in a scene having strong horizontal banding.

EXPERIMENT 2
DETECTION OF ROTATION IN A SCENE INSERT AS A FUNCTION OF INSERT SIZE, RESOLUTION DIFFERENCES, AND SCENE CHARACTERISTICS

BACKGROUND

The military tasks of air-to-ground or air-to-air target acquisition are very difficult to simulate with CGI systems. The simultaneous requirements of a large field of view and high resolution impose extensive design requirements on computer size and display techniques. The field of view desired for these military tasks is 360° minus the area masked by the aircraft structure. Savings in computer size/time requirements may be achieved by presenting low resolution images for the pilot's peripheral orientation cues and restricting the high quality image only to one or more small areas known as inserts. The feasibility of using high resolution inserts has been investigated as a means of reducing the computer size and display limitations without jeopardizing the essential characteristics of the visual environment.

There are three potential methods of using inserts. The first involves using various locations within the large field of view to place an insert containing a specific target for air-to-air combat training. However, if the insert is identifiable by any of its non-target parameters, then the simulation of a real-world target acquisition task has been poorly accomplished, as the search function is the largest contributor to target acquisition time. If the pilots learn that all they have to do is locate the insert and then identify the target within that particular area, they will consume inordinately little time in target acquisition, have too much time for other tasks, and learn little about target acquisition that will transfer to a real combat mission. Search time may be increased by the random location within this very large field of view of a large number of inserts, one or two of which may contain targets. This multiple insert design has the requirement that each of the inserts containing a target not be easily recognizable as different from the other "confusion" inserts. Search time increases as the number of alternatives that must be searched increases, and 16 to 32 inserts should be a sufficient number to properly simulate the search function in air-to-air and air-to-ground target acquisition. So the limitations of this method of using an insert are as follows: (a) small inserts are required to obtain the resolution needed if a raster scan system is used, (b) the design is complicated by the large number of inserts which would be used as confusion areas, increasing computational and display complexity, and (c) all the generic insert parameters would have to be subthreshold, relative to the general background of the remainder of the field of view. The perceptual thresholds for many of these parameters are not currently established.

In the second technique or method, the insert is slaved to the pilots' head orientation. As the pilots turn their head, the high resolution insert follows the head orientation and the relatively large area remains centered in front of the head. Man's visual system would dictate at least an intermediate-size insert because eye motions up to 30° may be used before a head motion is included as part of a search sequence. If this ± 30° range for eye movements without head motion is experimentally established, the field of view for the insert would have to be about 60° vertically and horizontally. If such a field of view were used with a requirement of one arc minute of resolution also imposed, the system would require about 3400 active raster lines in the insert. Current projectors which could be slaved to the head motion do not have the capability of displaying this many lines per channel. There is need for research to determine what the influence would be on performance of using head slaved inserts smaller than 60°.

The third method of using an insert is to slave the insert not only to head motion but also to eye motion within the volume of the head motion. The requirements of such a system are as follows: (a) it should be small enough in size and light enough in weight to be head-mounted, and (b) it should be accurate enough that the image would stop with the end of a saccadic eye movement. Overshooting, lags, or vibration of the image would induce poorer visual performance, pilot induced oscillations (PIO), and possibly motion sickness. These requirements are currently beyond the state of the art.

The first and third method of using inserts could both use relatively small inserts. In the latter case, an insert size could be selected such that the borders of that insert fall sufficiently far from the fovea that the lower resolution of the parafovea would preclude perception of the edge of the insert. The smaller the insert size, without its intruding into visual performance, the easier it would be to obtain high resolution within the insert. A 3° diameter insert could have 250 active TV lines and represent a visual resolution capability of 2/3 arc minute. This would be quite comparable to the "Landolt C" visual resolution of most pilots. An 8.5° diameter insert could be used with today's technology of a 1000 line system (715 active TV lines) to give the same resolution, and a future 2000 line system (1420 active TV lines) could provide a 16° field of view. A 16° field of view slaved to the eye should prove to be adequate. However, the limitation here is the technology of coupling the insert with the eye position as well as the head position.

The goal of visual flight simulation design is to produce a display system that can take full advantage of CGI signals, as well as provide adequate luminous intensity, realistic scene movement and velocities, a large field of view and an area of interest for a target-associated insert with high resolution. The major problems are in stabilizing and matching this area of interest (target insert) to the surrounding scene such that the high resolution image is provided with minimal scene distortion, misalignment, or intrusiveness. Since line scan imagery is one of the current display techniques, raster line density may be one of the recognizable differences between the insert and peripheral portions of the display. Discrimination by raster line density differences rather than by existing misalignment may decrease as scene complexity increases.

THE PROBLEM

The problem of this experimental investigation was to determine the just noticeable rotation of an insert as a function of (a) the size of the central insert, (b) the comparative number of raster lines between insert and peripheral field, and (c) the complexity of the scene. The following hypotheses were tested in making this investigation:

Hypothesis 1: The size of the scene insert will have a proportional effect upon the ability of the observer to detect rotational misalignment of the insert.

Hypothesis 2: Increasing the raster line density ratio between the insert and the surrounding scene will lower the detection threshold for rotational misalignment of the insert.

Hypothesis 3: The more complex scenes, particularly where there are more "straight lines" in the scene, will make rotational misalignment of the insert easier to detect.

METHOD

Apparatus

For this study, we used three types of CGI scenes, representing different levels of scene complexity: on the runway, ground to air, and approach to runway. These scenes were the same ones used in the display joints study (Experiment 1). The 4 x 5 inch transpositives were used to produce 35mm slides with the rotated insert and raster densities built into them. A total of 180 35mm slides were made to represent four levels of raster density ratios, three levels of insert size, three levels of scene complexity, and five levels of insert rotation.

Basically, each slide was developed using the double exposure technique (described earlier), with one exposure for the surround and a second exposure for the insert scene. In between the exposures, the rotation was inserted using precise positioning (.002 mm accuracy) on a large Mann Comparator, on which were mounted the 4 x 5 transpositives and the 35mm camera. Registration pins on a glass plate for location accuracy and pairs of masks precisely cut on a Coordinatograph and reduced onto Kodalith film for scene masking and for the raster grid were used. These slides were presented to the pilot/observers using a random access projector and a rear projection screen with a display size of 28° vertical x 42° horizontal.

Experimental Design

For this study, 3°, 6°, and 12° (at the eye) square inserts located in the center of a 48° horizontal by 28° vertical field of view were used. The rotational misalignment levels for the insert portion of the scene (the insert frame itself was not rotated) were set at 0°, .25°, .50°, 1.0°, and 2.0°, measured as rotation around the center of the scene.

For the different raster line densities, a square wave line grid with a 2:1 line width to space width upon the insert and surrounding scene at four levels of spatial frequency ratios: 0:0, 1:1, 1:33 and 1:11 was superimposed. The 1:1 ratio represented one line and space per arc minute; .33 and .11 represented, respectively, .33 and .11 line pairs per arc minute. In the 0:0 condition, no line grid for either the insert or the surround was used. For the other three ratio levels, the insert had a grid spatial frequency of 60 cycles per degree and the surrounding scene had grid spatial frequencies of 60, 20, and 6.67 cycles per degree. These correspond to 1680, 560, and 187 line pairs over the 28° vertical field. The experimental design is shown in Figure 18.

Observers

After examination of visual skills, 16 pilots from McChord AFB were selected to serve as test subjects. These pilot/observers had a visual acuity of at least 20/20 corrected.

Procedure

The 180 slides composing the stimulus material were randomly arranged in three slide trays for presentation on a rear screen projector. The pilot/ observers were seated at a distance of 68 centimeters from the screen, and the projector was situated such that the scene field of view provided the observer with 42° horizontal and 28° vertical.

Each of the 16 observers saw all 180 slides. Their task was to determine if the insert appeared to be rotated relative to the peripheral portions of the scene and if so, in which direction. The required response was one of three categories (aligned, rotated clockwise, or rotated counterclockwise). A short set of training slides was given each observer prior to testing.

Analysis of Results

When data collection was completed, the data were submitted for computer analysis. We used ANOVA techniques to explore main effects and their interactions after the data were binomially scored into the perceptual performance categories of percentage correct detections and percentage of aligned responses.

RESULTS AND DISCUSSION

Rotation of Insert Scene

Table 6 provides the results of the ANOVA of correct responses along with means and standard deviations for the main effects. As shown, each of the four main effects (insert size, raster density ratio, insert rotation, and scenes) was strongly significant ($p < .01$), although raster density ratio was a little weaker than the other three. In addition, the two factor interactions of insert size by insert rotation and insert size by scene were also significant at the $p < .01$ level, as were all of the three and four factor interactions.

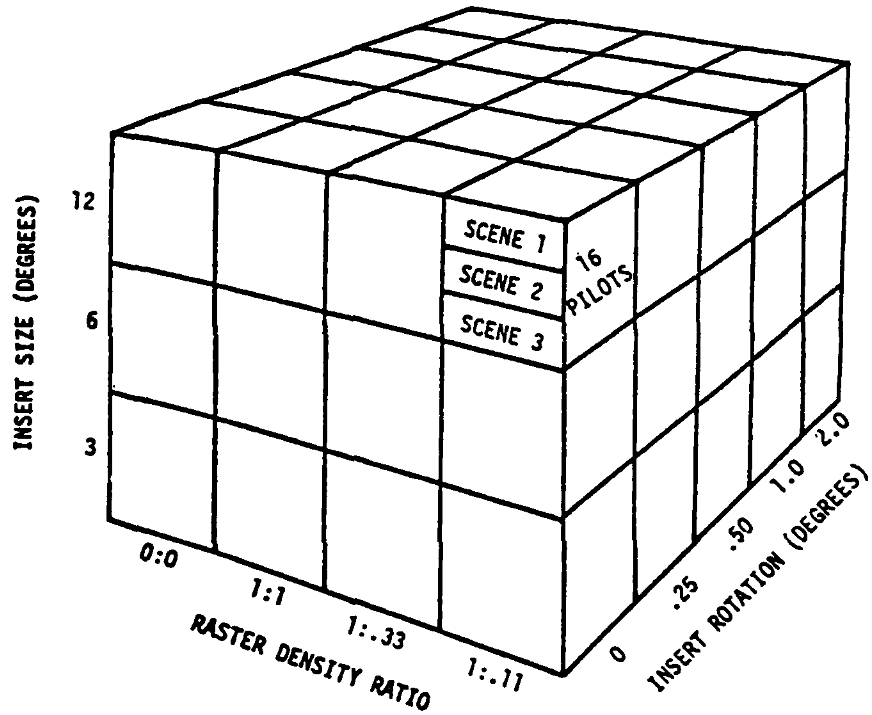

Figure 18. Experimental design for study of insert rotation.

Table 6. ANOVA Summary for Percent Correct Detections of Misalignment in the Insert Study

ANOVA TABLE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM /n-1	MEAN SQUARES			F
INSERT SIZE	517612.85	2/30	308806.42	F	=	168.79**
RASTER DENSITY	27881.94	3/45	9293.98	F	=	6.98**
IxR	9123.26	6/90	1520.54	F	=	1.81
MISALIGNMENT	856250.00	3/45	285416.67	F	=	164.25**
IxM	99505.21	6/90	16584.20	F	=	8.60**
RxM	13229.17	9/135	1469.91	F	=	1.80
IxRxM	39036.46	18/270	2168.69	F	=	2.24**
SCENE	272039.93	2/30	136019.97	F	=	55.61**
IxS	19730.90	4/60	4932.73	F	=	4.24**
RxS	12092.01	6/90	2015.34	F	=	2.23*
IxRxS	54574.65	12/180	4547.89	F	=	4.50**
MxS	18203.13	6/90	3033.85	F	=	2.77*
IxMxS	116588.54	12/180	9715.71	F	=	6.82**
RxMxS	57942.71	18/270	3219.04	F	=	3.77**
IxRxMxS	99244.79	36/540	2756.80	F	=	2.44**
PILOTS	363055.56	15				
IxP	54887.15	30	1829.57			
RxP	59895.83	45	1331.02			
IxRxP	75598.96	90	839.99			
MxP	78194.44	45	1737.65			
IxMxP	173550.35	90	1928.34			
RxMxP	110104.17	135	815.59			
IxRxMxP	261796.88	270	969.62			
SxP	73376.74	30	2445.89			
IxSxP	69852.43	60	1164.21			
RxSxP	81380.21	90	904.22			
IxRxSxP	181953.12	180	1010.85			
MxSxP	98602.43	90	1095.58			
IxMxSxP	256605.90	180	1425.59			
RxMxSxP	230807.29	270	854.84			
IxRxMxSxP	610338.54	540	1130.26			
TOTAL	5093055.56	2303				

* $p < .05$
** $p < .01$

MAIN EFFECT MEANS AND STANDARD DEVIATIONS

INSERT SIZE

	3°	6°	12°
MEAN	47.01	66.93	87.11
S. D.	49.94	47.08	33.53

RASTER DENSITY RATIO

	0:0	1:1	1:.33	1:.11
MEAN	72.57	65.80	66.67	63.02
S. D.	44.66	47.48	47.18	48.32

MISALIGNMENT (Rotation)

	.25"	.50"	1.0"	2.0"
MEAN	38.89	60.76	78.47	89.93
S. D.	48.79	48.87	41.14	30.12

SCENE

	Runway	Grnd-to-Air	Approach
MEAN	77.99	52.21	70.83
S. D.	41.46	49.98	45.48

" = Arc Seconds

Figure 19 depicts the effect of insert rotation on the percent of correct detections. From a low of about 39 percent with .25° of insert rotation, the correct detections rise to 90 percent with 2° insert rotation. This function appears quite smooth and approximates a linear relationship when the percent correct are plotted against the "log" of insert rotation. (See Figure 20.) The area of primary interest for this curve is the lower end (smallest scene rotation values) where correct detections of the misalignment first appear. As the plot shows, there was an average of 39 percent correct detections, even at the lowest rotation (.25°) This is just a few percentage points above the theoretical "chance" level of 33.3 percent for three response categories, and it would appear that perhaps another level of rotation (such as .1°) may have resulted in some additional useful data. However, as will be seen later, looking at angular scene rotation by itself is an inadequate view of the discrimination task and the responses to it.

It may also be argued the chance response level is not really appropriate because the condition that would produce "guessing" or "chance" responses (i.e., the inability to discriminate any differences) is required, by design, for one category of the available responses, specifically that of the "aligned" response. The "aligned" responses for the different level of scene rotation are plotted in Figure 21 and the analysis of variance in Table 7. When this response is to any of the conditions containing some insert rotation, it is an erroneous response; but, when it is to the condition which has no scene rotation, it is a correct response. These responses are grouped together as "errors" because they both represent situations in which the observer is unable to detect any misalignment or rotation of the insert scene. This situation may be relevant to the system designer, because, as the percentage of "aligned" responses begins to fall off and the observer starts to make correct detections of the insert scene rotation, a design specification for misalignment must be selected based on the impact of the detection of such misalignment upon the training task.

Figure 21 shows a steep decline in the percent of "aligned" responses between the 0° and .25° scene rotation conditions. The percentage of aligned responses under the 0° condition (approximately 70 percent) can be taken as a baseline response level, and it could be that additional, small amounts of insert scene rotation between 0° and 25° would show a more gradual transition from the 70-percent level. Such transition would indicate one or more of the small rotations were almost indistinguishable from the 0° rotation condition.

It is of some interest to consider the response level at .25° of insert scene rotation. Overall, the observers made 53 percent "aligned" responses to this condition. This is a level of rotation that is not detected about half the time and is judged as rotated, either in the correct (39 percent) or incorrect (8 percent) direction, the other half of the time. This level could be taken as an approximate 50 percent threshold for misalignment responses. while the 50 percent threshold for correct detections of misalignment would come at about 38° of insert scene rotation.

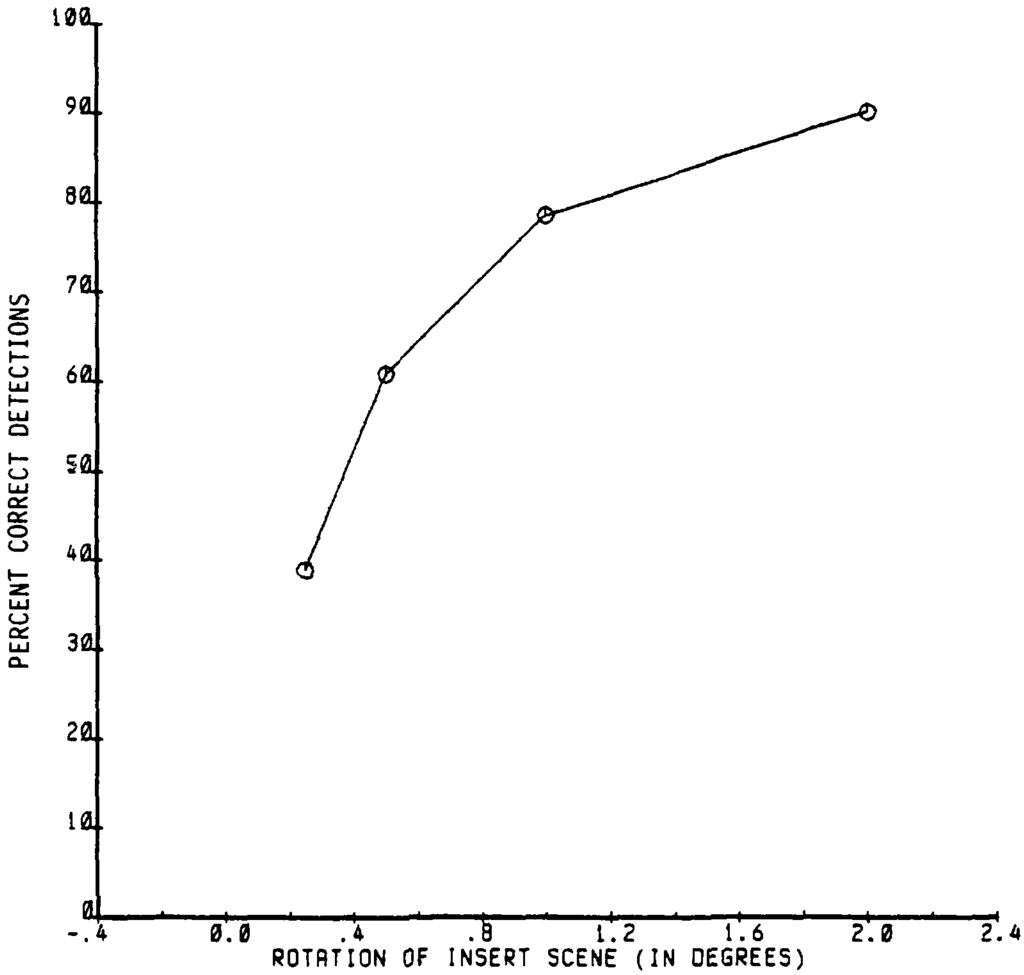

Figure 19. Percent correct detections as a function of insert scene rotation.

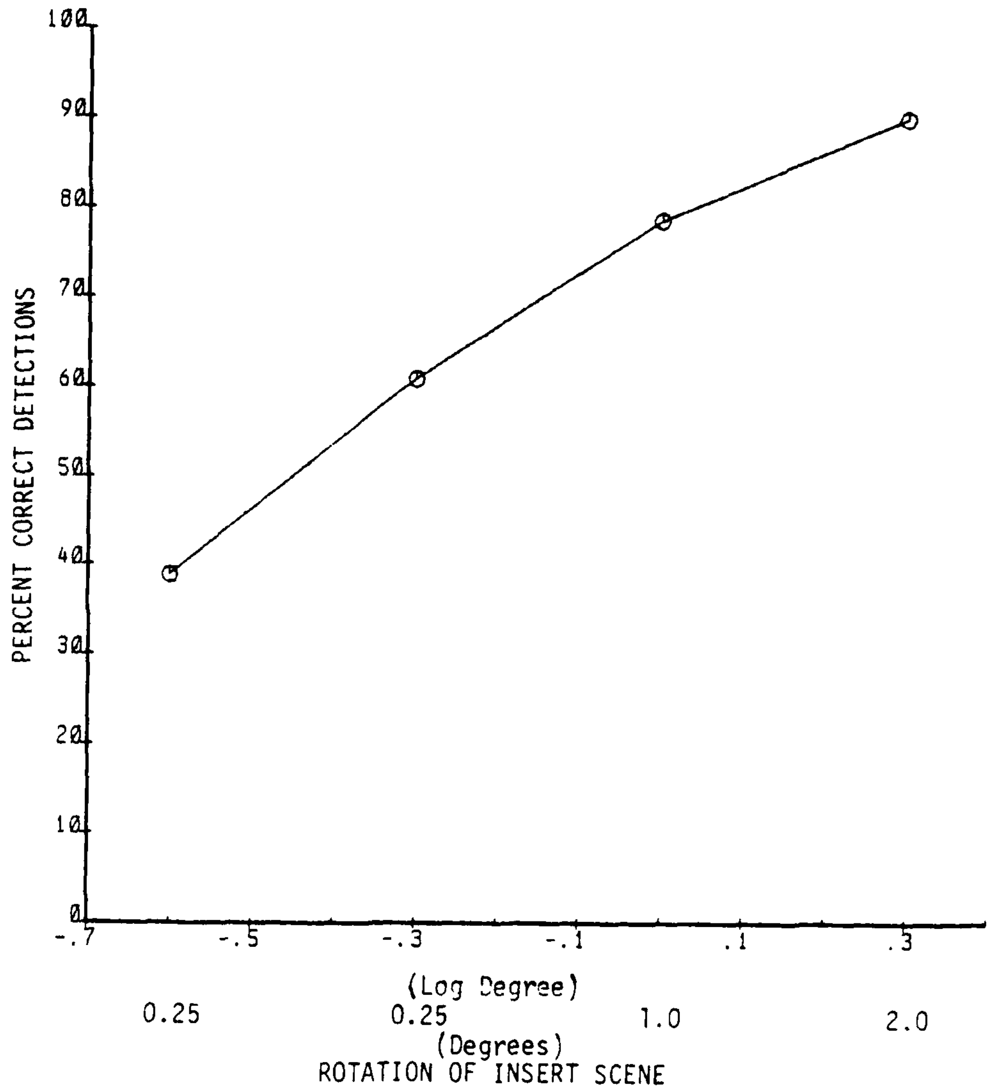

Figure 20. Percent correct detections as a function of the log of insert scene rotation.

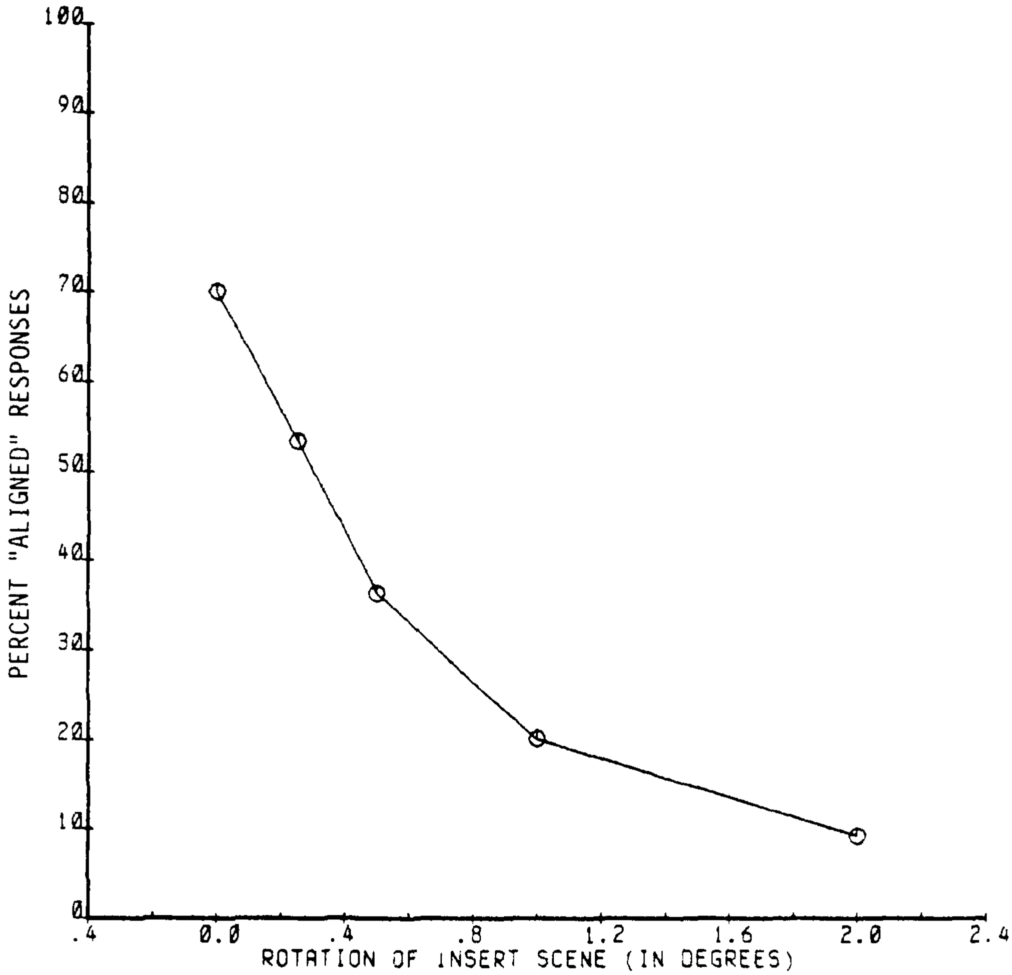

Figure 21. Percent "aligned" responses as a function of insert scene rotation.

Table 7. ANOVA Summary for Percent "Aligned" Responses to Misalignment in the Insert Study

ANOVA TABLE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM /n-1	MEAN SQUARES	F
INSERT SIZE	357527.78	2/30	178763.89	F = 70.23**
RASTER DENSITY	12041.67	3/45	4013.89	F = 2.37
IxR	12083.33	6/90	2013.89	F = 1.85
MISALIGNMENT	1395937.50	4/60	348984.38	F = 123.29**
IxM	206395.83	8/120	25799.48	F = 17.28**
RxM	45979.17	12/180	3831.60	F = 3.69**
IxRxM	61354.17	24/360	2556.42	F = 2.33**
SCENE	236298.61	2/30	118149.31	F = 25.64**
IxS	14263.89	4/60	3565.97	F = 2.06
RxS	20395.83	6/90	3399.31	F = 3.84**
IxRxS	60041.67	12/180	5003.47	F = 4.68**
MxS	50645.83	8/120	6330.73	F = 5.27**
IxMxS	103270.83	16/240	6454.43	F = 4.52**
RxMxS	67937.50	24/360	2830.73	F = 2.86**
IxRxMxS	172979.17	48/720	3603.73	F = 3.03**
PILOTS	561097.22	15		
IxP	76361.11	30	2545.37	
RxP	76180.56	45	1692.90	
IxRxP	98027.78	90	1089.20	
MxP	169840.28	60	2830.67	
IxMxP	179159.72	120	1493.00	
RxMxP	186909.72	180	1038.39	
IxRxMxP	395756.94	360	1099.32	
SxP	138256.94	30	4608.56	
IxSxP	103847.22	60	1730.79	
RxSxP	79715.28	90	885.73	
IxRxSxP	192513.89	180	1069.52	
MxSxP	144243.06	120	1202.03	
IxMxSxP	342506.94	240	1427.11	
RxMxSxP	355840.28	360	988.45	
IxRxMxSxP	857243.06	720	1190.62	
TOTAL	6774652.78	2879		

* $P < .05$
** $P < .01$

MAIN EFFECT MEANS AND STANDARD DEVIATIONS

INSERT SIZE

	3°	6°	12°
MEAN	51.46	37.92	24.17
S. D.	50.00	48.54	42.83

RASTER DENSITY RATIO

	0:0	1:1	1:.33	1:.11
MEAN	34.44	38.06	39.44	39.44
S. D.	47.55	48.59	48.91	48.91

MISALIGNMENT (Rotation)

	0"	.25"	.50"	1.0"	2.0"
MEAN	70.14	53.47	36.28	20.14	9.20
S. D.	45.80	49.92	48.12	40.14	28.93

SCENE

	Runway	Grnd-to-Air	Approach
MEAN	29.90	50.52	33.13
S. D.	45.80	50.02	47.09

" = Arc Seconds

Scenes

The effects of three scenes on correct detections of different levels of insert scene rotation are shown in Figure 22. The responses of each scene generally follow the same trend, although there is a significant overall displacement between the scenes, as signified by the strong F ratio in the ANOVA. Scene 2, the ground-to-air scene, shows a significantly lower level of correct detections than do scenes 1 and 3. Since this scene is predominantly "sky," there are much fewer straight lines or "edges" to be broken by the insert scene rotation than is the case for either of the other two scenes. In fact, the area covered by the insert, even for the largest (12° condition), contains only sky with no terrain features. That the level of correct responses to rotations in this scene are not even lower is probably due to the "horizontalness," or horizontal structure provided by the raster format, especially the simulated raster grids superimposed over the surround and insert areas to provide different ratios of insert-to-surround raster density.

With its highly structured runway scene, scene 1 results in the overall highest level of performance at 78 percent correct detections. Scene 3 is not far behind, with correct detections made 71 percent of the time. These are both significantly better than the 52 percent garnered by scene 2. At the lowest level of insert scene rotation (.25°) the percentages of correct detections are 24 for scene 2, 45 for scene 3, and 48 for scene 1. The 50 percent correct detection thresholds would fall at .27° for scene 1.

The curves for scene effects also approximate a linear relationship if plotted as a function of the log of insert scene rotation, although there is some "bending" of the curves for scenes 1 and 3 as the correct detections approach 100 percent.

Insert Size

The ANOVA showed strong effects on detections of insert scene rotation for the variable of "insert size." The three sizes of the square insert (3°, 6°, and 12°) show an increasing enhancement of correct detections as a function of size. The overall correct detections were 47 percent for the 3° insert, 67 percent for the 6° insert and 87 percent for the 12° insert. These effects are plotted in Figure 23 as a function of insert scene rotation. It is no surprise that increasing the insert size should contribute so much to detections since, for any one level of insert scene rotation, going from 3 to 6 degrees, or from 6 to 12 degrees, doubles the actual vernier displacement or mislaignment between corresponding segments of the scene in the insert and the surround. Since the levels of insert scene rotation are also multiples, and these result in almost equal percentages of correct responses as illustrated by the dashed lines in Figure 24, the percent correct detections may be plotted against six intervals of vernier displacement, as in Figure 25, and as a log vernier displacement in Figure 26. The latter figure describes an ogive function (less the lower shoulder) that is typical of psychophysical threshold investigations.

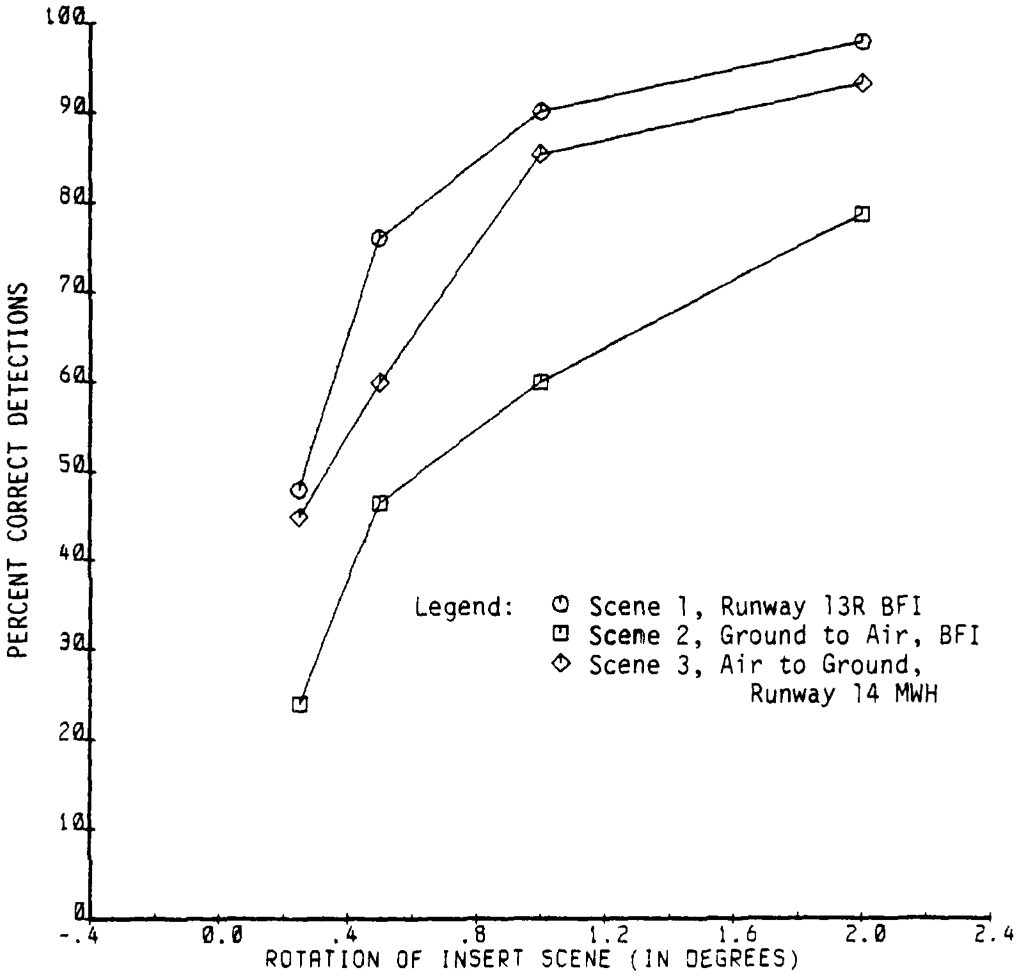

Figure 22. Percent correct detections for each scene as a function of insert scene rotation.

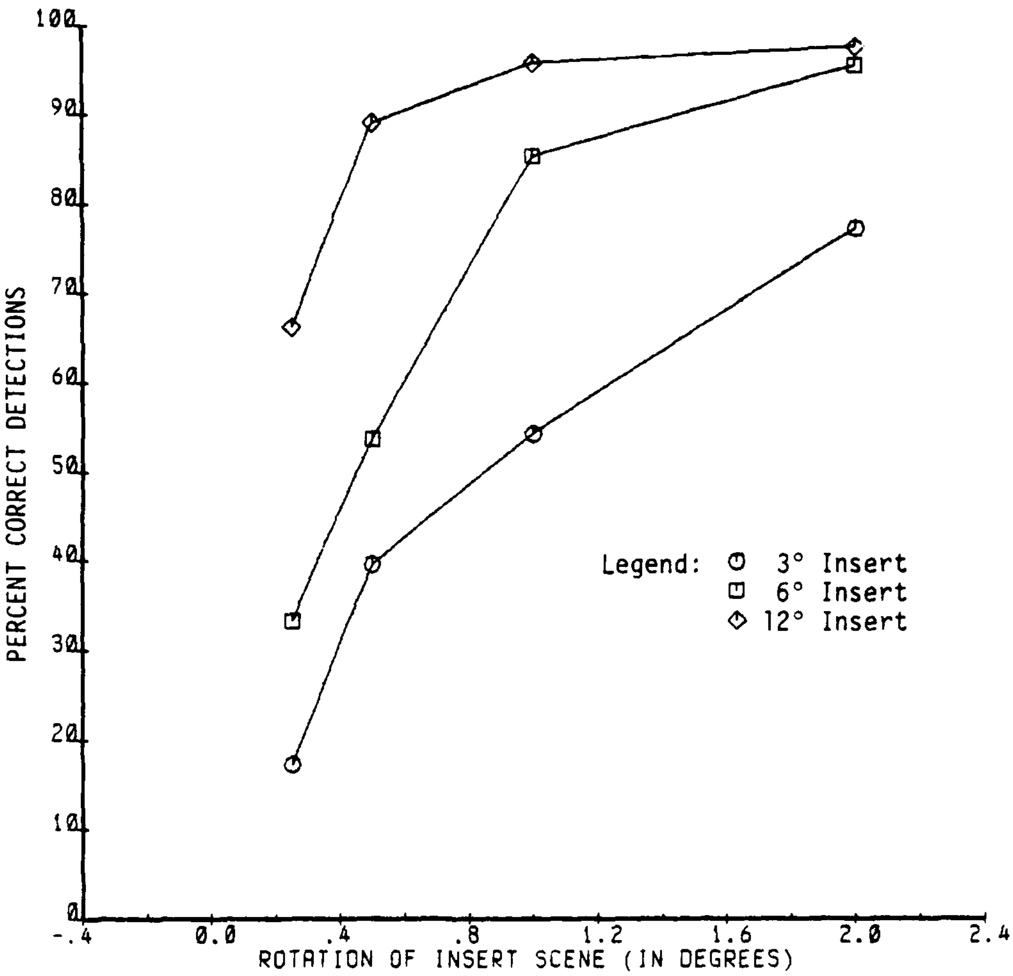

Figure 23. Percentage of correct detections for each insert size as a function of insert scene rotation.

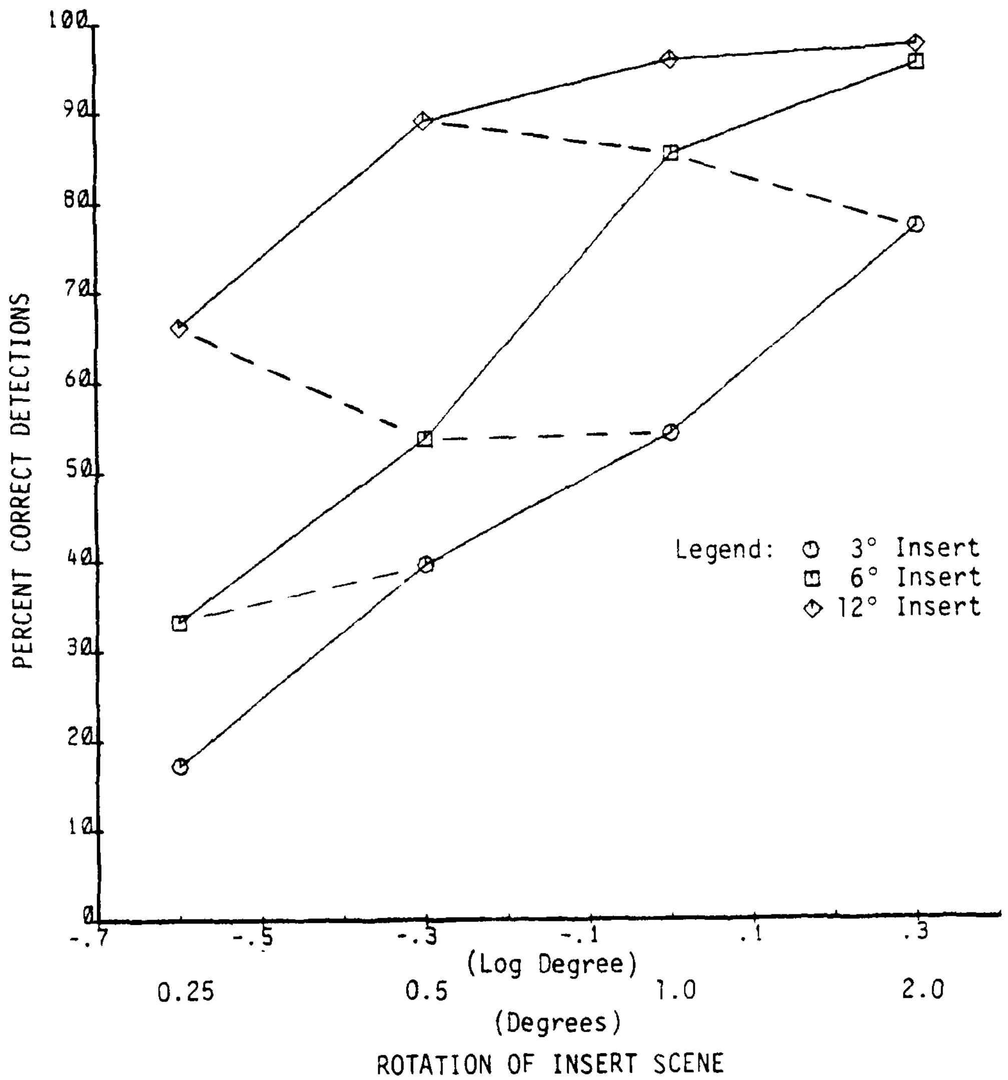

Figure 24. Percentage of correct detections for each insert size as a function of log of insert scene rotation.

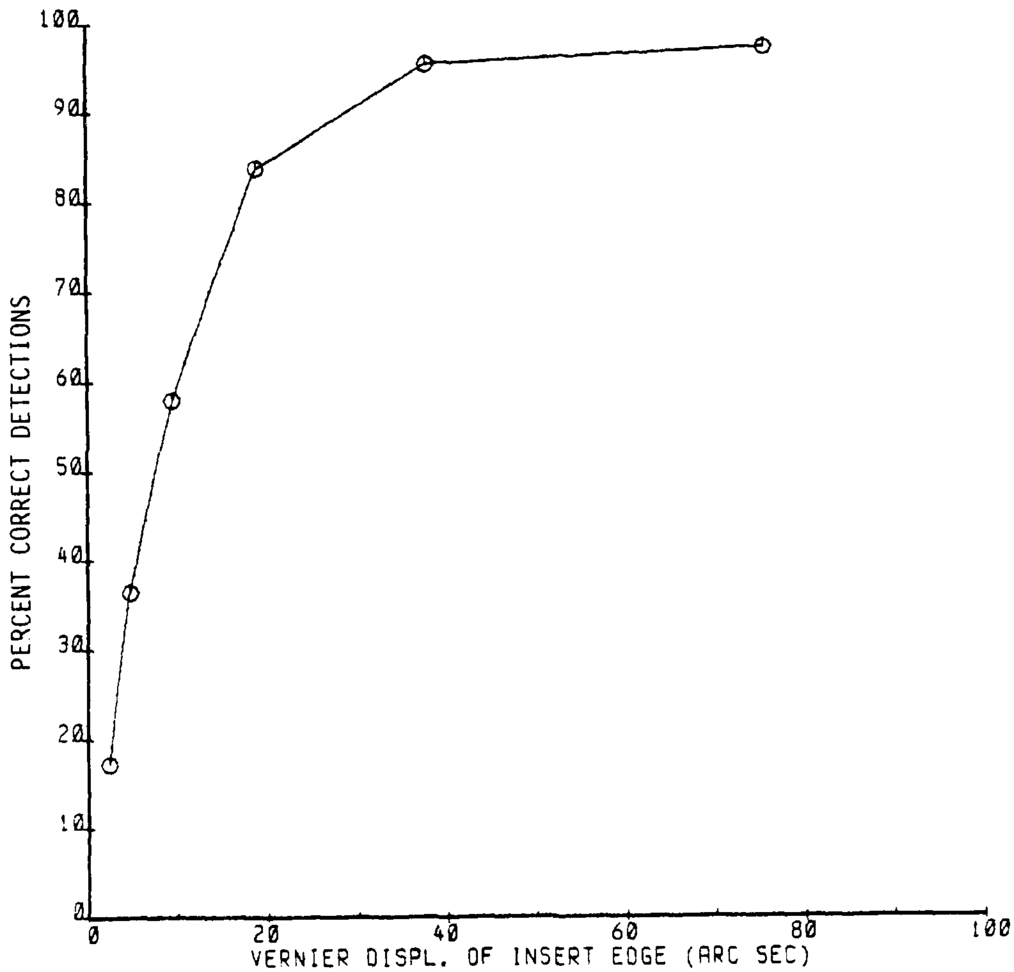

Figure 25. Percentage of correct detections of rotation of inserts as a function of vernier displacement at the insert perimeter.

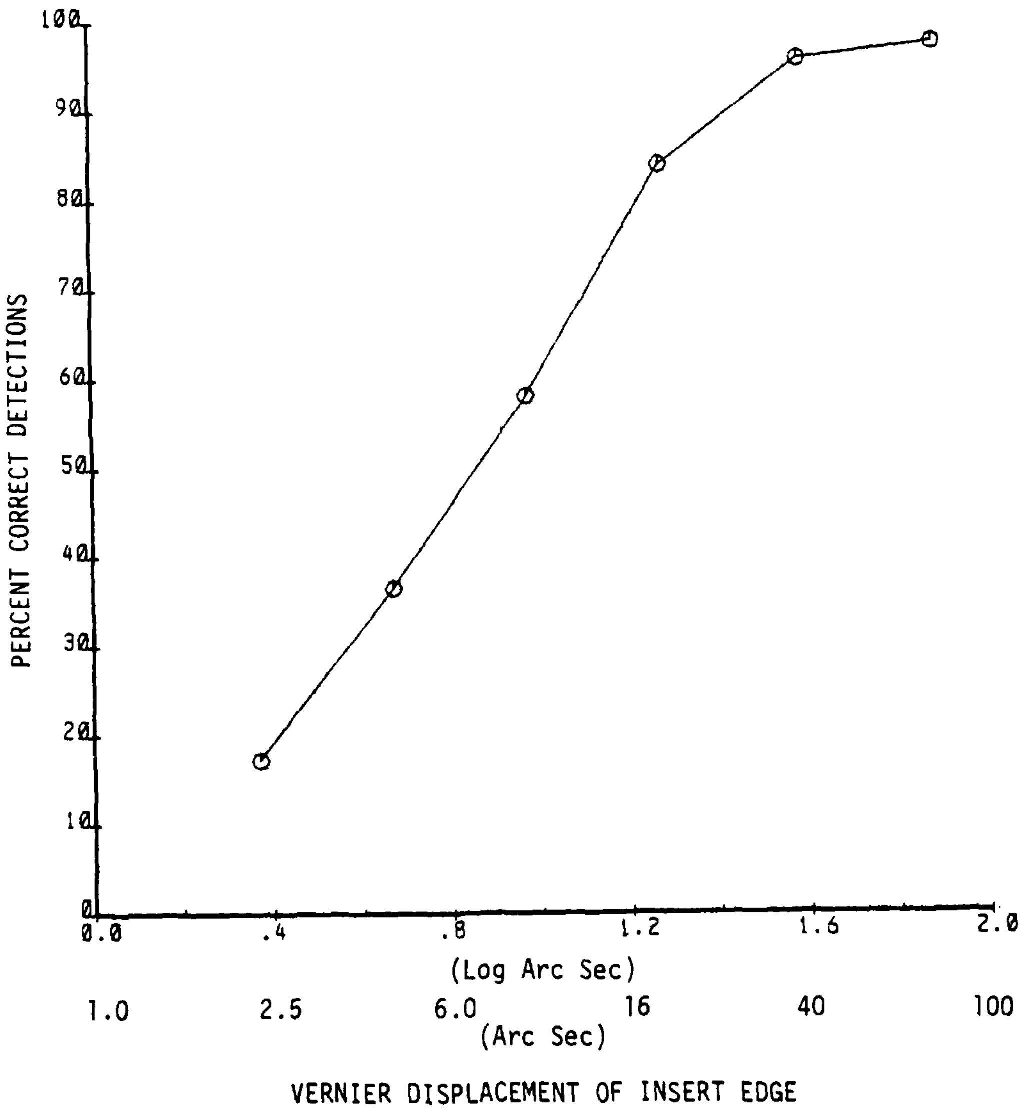

Figure 26. Percentage of correct detection of rotation of inserts as a function of log vernier displacement at the insert perimeter.

Using the graphic method of determining thresholds (i.e., by reading the X value for Y = 50 percent from the curve), the 50 percent threshold would occur at .85 log arc second or 7.1 arc seconds. This threshold value is almost identical to the vernier threshold data included in the Phase I report (Kraft and Anderson, 1980). The vernier threshold with a separation of 20 arc minutes was 7 arc seconds when the stimulus was two high-contrast vertical lines against a homogeneous background. The threshold of 7.1 arc seconds obtained in this experimental investigation has no separation but does have three different and relatively complex scenes as backgrounds.

Confirmation that the threshold is within acceptable tolerances is found in the study of aligned responses. Figure 27 and the graphic method of threshold determination leads to a threshold of 6.25 arc seconds. It might be concluded then, that for 50 percent thresholds, the value lies between 6.25 and 7.1 arc seconds depending on the response category used in the determination of the threshold.

The specification for any insert rotation limits in a CGI system is $\pm$ 7 arc seconds and will be a difficult one to achieve. However, if designers wish to use only one insert of high resolution to display the target and plan that this insert is not identifiable by any non-target parameters, they must align the insert with the surround equals < 7 arc seconds.

Raster Lines and Insert Rotation

The narrow tolerances for rotation imposed by the pilot's skill in detecting vernier displacements as evidence of rotation is not solely a product of the presence of raster lines in the display. Raster lines will serve as distinct cues for misalignment by rotation however, pilots can discriminate these small rotations in a scene without the presence of raster lines. Figure 28 illustrates that the best performance in discrimination of rotations occurs at all rotation values by the scenes without raster lines. The raster line density does influence discrimination in the order of reduced discrimination as the density ratios become larger. That is, when the insert has one line/space per arc minute and the surround has a raster density of one line pair per 9 arc minutes, discrimination is lower for the average of all rotation magnitudes.

The scene elements without the raster lines provide sufficient comparisons for pilots to discriminate the rotations (with 7 arc seconds as the 50-percent threshold). The visual discriminations of the vernier misalignments in these data were accomplished with eye movements. The most sensitive parts of the retina could be used by the pilots in examining the edges of the insert. Thus, the larger the insert, the better is the discrimination, which was directly proportional to the angular separation of elements at the edge of the insert.

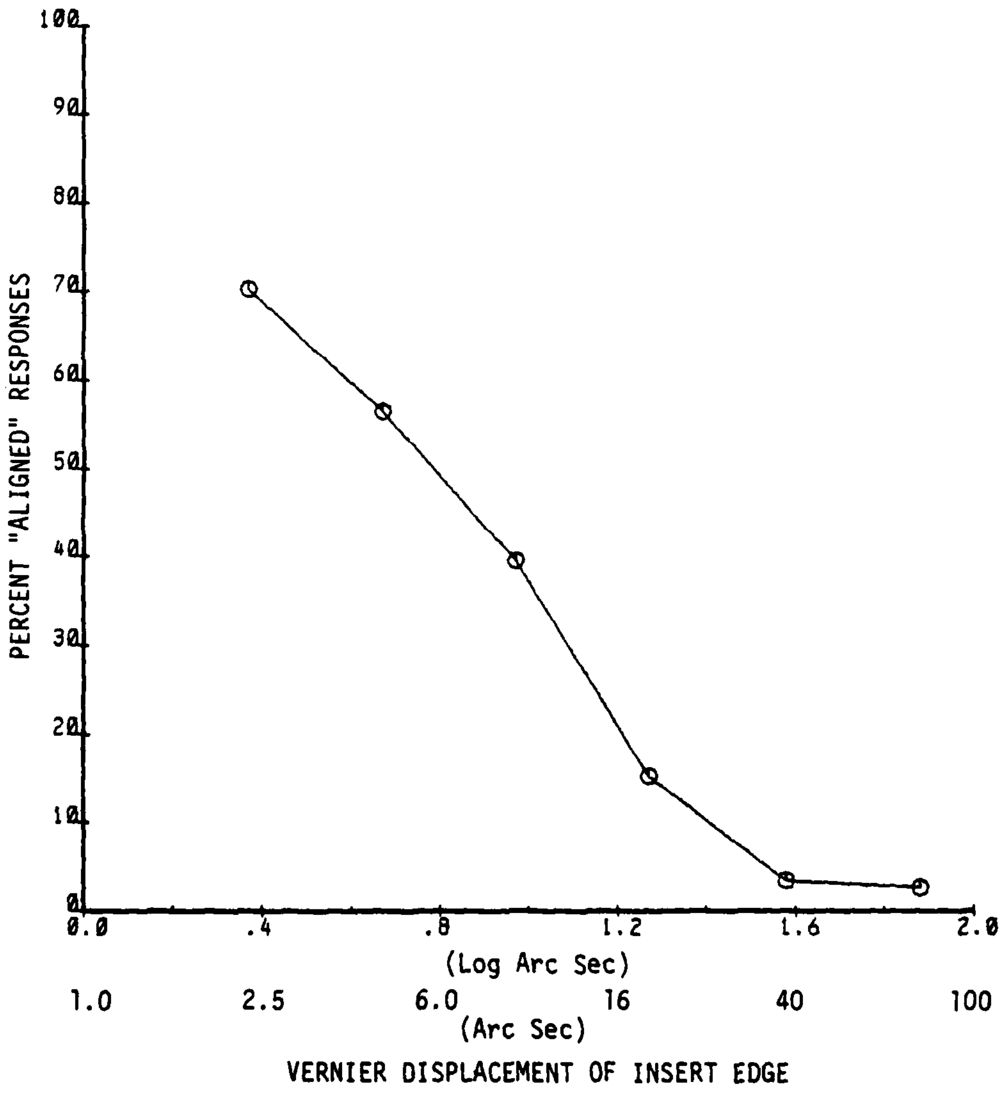

Figure 27. Aligned responses of rotation of inserts as a function of log vernier displacement at the insert perimeter.

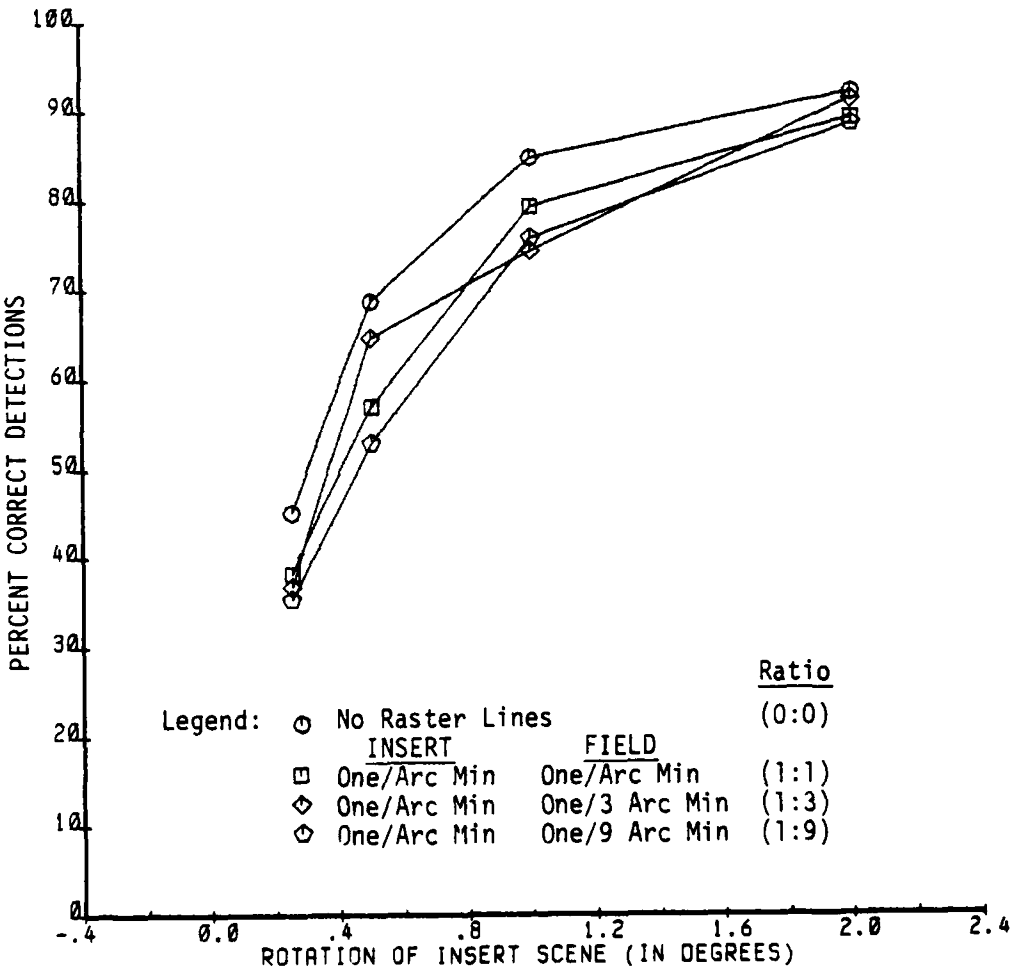

Figure 28. Percentage correct detections for each raster line density as a function of insert scene rotation.

Insert size would be differently related to rotation discrimination if the center of the insert was slaved to the line of sight of the eye. That is if the behavioral axis of the eye were tracked perfectly by the center of the insert, then the edge of the largest insert would be the most poorly resolved. However, until such a slave system can be developed and applied, the designer must contend with a requirement for rotational error limit that produces an edge displacement of $\pm$ 7 arc seconds.

As a main effect, raster line density is statistically significant ($p =< .01$) in the analysis of percent correct detections. (See Table 6.) In this analysis, all interactions that include raster line density as a source of variation are also significant with the exception of IxR. In the analysis of "aligned" responses, raster line density is not significant as a main effect nor as an interaction with insert size. The remaining first and second order interactions are significant. (See Table 7.) Hypotheses from these data should be conservative with respect to raster line desnsity, as the one cycle per arc minute frequency was not precisely resolved by the slide x projector display. However, as discussed earlier, the easiest discriminations of rotational error occurred without raster lines.

Conclusions

Under the experimental conditions of this study, it was found that the detection of insert rotation was seriously influenced by the spatial displacements such rotations cause at the interface between the insert and the main scene. The data indicate that displacements of less than approximately 7 arc minutes of visual angle had a probability of detection of less than 50 percent.

The presence or absence of raster lines in the insert had no significant effect on the results. This may have been due to the fact that the finest raster lines were poorly resolved in the stimulus material. This conjecture must however be considered in the light of the following facts:

1. Selection of rotation was most sensitive for the insert with no raster lines.

2. In practical CGI systems, the insert raster lines have low visibility because of the small visual angle they subtend.

SUMMARY: INSERT STUDY

The purpose of this study was to determine the scan line effects of rotation, size and scan line density on the detectability of small inserts in CGI imagery, with the goal of developing guideline data for use in the specification and design of visual scene generators. In applying these data, the conditions of this study must be considered.

1. All three scenes represented daylight conditions.

2. State-of-the-art (1980) operational CGI imagery was used.

3. Static rather than dynamic scenes were used.

4. The experimental design chosen permitted the study of a larger range of conditions at the expense of sensitivity of the detection differences among the conditions.

5. All subjects were experienced Air Force MAC pilots.

The basic findings of this study were:

1. Spatial displacement of image features at the interface between the insert and the main scene is the most important factor in determining the detectability of the rotation of the insert. Insert size and rotation combinations which produce such displacement of less than 7 arc minutes of visual angle were detected less than 50 percent of the time. This number is consistent with the laboratory data on vernier acuity.

2. Scan line density had little effect on the detection of insert rotation. This result may have been due to the low visibility of the scan lines in the insert. This drawback is somewhat offset by the fact that the visibility of these scan lines is very low due to the small visual angle subtended.

Designers who anticipated using inserts that are not discernible by rotational errors, must develop systems that have less than 7 arc seconds displacement at the edge of the insert. These specifications would not apply to an insert accurately slaved to the behavioral axis of the eye. However, until such a system is developed and proved applicable, the above specification should hold for rotational error limits.

REFERENCES

Berry, R. N. Quantitative relations among vernier, real depth, and stereoscopic depth acuities. Journal of Experimental Psychology, 1948, 38, 708-72.

Cameron, E. H. & Steele, W. H. The Poggendorff illusion. Psychological Monographs, 1905, 7, 83-111.

Green, R. T., & Hoyle, E. M. Adaption level and the optico-geometric illusions. Nature, 1964, 201, 1200-1.

Helson, H. Adaptation level theory. New York: Harper and Row, 1964.

Judd, C. H., & Courten, H. C. Zollner illusions. Psychological Monographs, 1905, 7, 112-39.

Kraft, C. L., Anderson, C. D., & Elworth, C. L. Psychophysical criteria for visual simulation systems. AFHRL Operations Training Division, TR 79-30, Williams AFB, Az. May 1980. AD-A084 776.

Leibowitz, H. & Toffey, S. The effects of rotation and tilt on the magnitude of the Poggendorff illusion, Vision Research, 1966, 6, 101-103.

LeMaster, W. D. & Longridge, T. M., Jr. Area of interest/field-of-view research using ASPT. AFHRL TR-78-11, AD-A055 692. Williams AFB, Az: Flying training division, Air Force Human Resources Laboratory, May 1978.

Robinson, J. E. The psychology of visual illusion. London Hutchinson and Co., Ltd., 1972.

Tong, L. & Weintraub, D. J. Contour displacements and tracking errors: probing twixt Poggendorff parallels. Perception and Psychophysics, 1974, 15, 258-268.

Wagner, H. L. Simultaneous and successive contour displacements, Ph.D. Thesis, University of Wales, 1969.

APPENDIX A

ACTUAL ANGULAR SEPARATION ACHIEVED IN SLIDES

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The major independent variable of the study of the separation between a forward and forward oblique window called for gaps between these windows of five different magnitudes. The desired magnitudes or widths of these gaps were .125, .250, .50, 1, and 2 degrees of angular separation. The final product used in the experiment was 120 35mm slides in paper mounts. To achieve these different separations it was necessary to develop masks that could be laid over the original stimulus material in succession such that a black strip was formed between the forward scene and the left forward oblique scene. These masks were made on the Borrowdale camera to an accuracy of less than 0.001 inch. The displacements and rotations were made by movement of the stage supporting the copy material on the Mann Comparator. This stage could be controlled within 0.001 millimeter and 0.01° in rotation.

Since there were a large number of these 35 transparencies to make, the most cost-effective equipment was a 35mm camera. The essential requirement was to make two exposures on the same frame. In the modern single lens reflex camera design, the film advance is also coupled to the shutter cocking mechanism. It was determined that no camera within The Boeing Campany had a controlled device which would freeze the position of the film and allow the camera to be cocked without some transport movement of the film. A survey of available cameras led to the rental of a Canon A-1. This camera has a special lever on the film advance mechanism wherein the film can be unlocked and the shutter can be cocked without advancing the film. The film advance lever also cocks the shutter as it moves through an arc of about 120°. When one releases the mechanism which advances the film, the lever moves through the same arc, but in the last 10° of that arc will nudge the film forward a slight amount. The experimenters discovered this in their initial examination of the rental camera. The technique of avoiding this is to advance that lever until the click of the completion of the cocking mechanism is heard, and then the lever is returned to the zero position. The clutch release mechanism, that frees the film advancing sprocket wheel, is dependable. There is a ratchet mechanism that does not allow the film to move backward toward the cassette. However, a slight movement is possible within the dimensions of the ratchet steps. When the clutch release mechanism was activated it would pull the film against the ratchet if there was a drag back toward the cassette . If there was no such drag, the film remained in the position of the fartherest advanced position of the sprocket wheel. The films that were made for the displacement part of this experiment were initially done with the camera mechanism unmodified. (This information is included to assist any research person who wishes to duplicate this experiment or to use double exposures in preparing stimulus materials).

An examination of films made for the displacement slides revealed some unusually narrow gaps or separations. These films were re-made and the ones closest to the designed width were chosen for the experiment. The taking situation was modified in making the slides for the study of angular separations on the rotation of images. The photographic exposure of the film was done in exactly the same manner previously described; however, one modifiecation was made on the camera setup. A weight attached to a small tape was applied to the re-wind knob. This put a light and constant return pressure on this knob. The weight was designed to pull the film until the sprocket wheel seated against its stop. This decreased the constant error from 0.031° of an average mean difference from the standard to an average mean difference of 0.001°. The average variance was increased, and the square root of this is .08°, or just about twice that of the technique used with the displacement slides. So the technique decreased the constant error, but increased the variable error. The actual values of these conditions are shown in Table A1 and a depiction of the differences is shown in Figure A1.

We used a third technique in the study of the rotation of inserts. We did not use the double exposing mechanism of the camera. Instead, the initial exposure was made by placing the camera on the "bulb" setting, opening the shutter, firing the electronic discharge lamp, and then putting a lens cap over the lens. Then we changed the conditions to be photographed, uncovered the lens by removing the lens hood, tripped the strobe light for the second time, and finally closed the shutter. This technique has the advantage of no movement of the film because no pressures were imposed beyond that which had been initially set up on the film. However, the exposure was deregulated to a degree, because some light had to exist in the room so that the experimenters could locate the lens cap and the trip and locking mechanism and could move about the room with some degree of safety. So the speed with which the lens cap was placed over the lens after the initial flash could cause variations in exposure. Were there some future need for a replication of this technique, we would recommend that the secondary large field Packard shutter be installed over the external surface of the lens. Then the two exposures could be precisely controlled by the emission characteristics of the strobe.

Table A-1

Width of Gaps

Empirically determined separations (in degrees) between forward and left-forward channels in the simulated scene, the variation (σ) among the 12 slides, and the average difference from the design widths.

	DESIGN SEPARATIONS (DEGREES)				
Conditions	0.125	0.250	0.50	1.00	2.00
Average separation in the displacement slides	0.088	0.228	0.466	0.958	1.98
Standard deviation in the displacement slides	0.054	0.046	0.050	0.059	0.036
Difference from design widths	-0.037	-0.022	-0.004	-0.042	-0.022
Average separation in the rotation slides	0.139	0.245	0.51	1.03	2.00
Stand. deviation in the rotation slides	0.060	0.077	0.074	0.057	0.117
Difference from design widths	+0.014	-0.005	+0.008	+0.031	+0.003

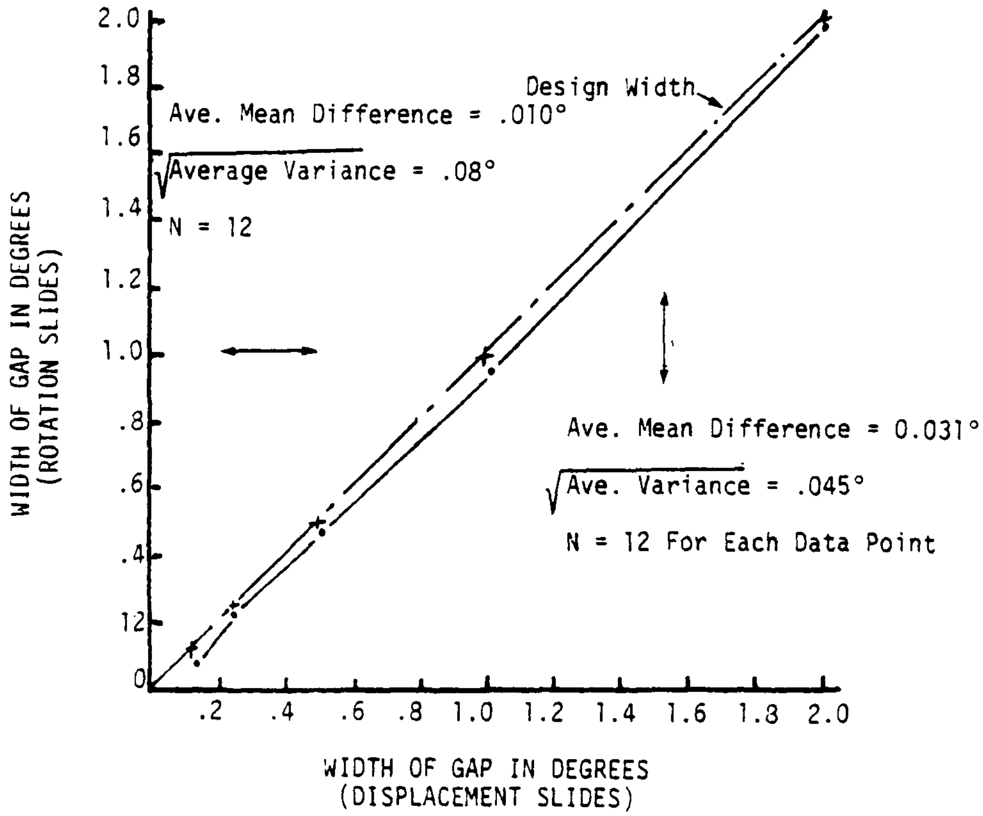

Figure A1. Average angular separations for each 'gap' size compared with design width (angular values pertain when the lateral field of view is 42 degrees).

APPENDIX B

RATIONALE FOR STATISTICAL ANALYSIS METHODOLOGY

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The experimental designs developed for these two studies are best described as factorials with repeated measures. There are three primary characteristics of this design: (a) the treatments consist of all combinations of the levels of all treatment variables (factorial experiment), (b) each subject is observed under each treatment combination (repeated measures), and (c) a single score is derived for each subject under each treatment combination. This design is sometimes also referred to as a randomized block design with blocking on subjects. All independent variables were considered fixed effects, except that the pilots or "subjects" variable was a random effect as usual.

The factorial design is especially suited to ANOVA techniques because the effects of the interactions of the independent variables, as well as the main effects, are calculated and tested for significance in a single, simple, procedure. With the pilots (subjects) as a random variable, the treatment effects, both main and interactions, are tested against the F-distribution using the treatment x subjects interaction in the denominator. Since in most of the ANOVAS, the higher order interactions are significant, no attempt was made to pool error terms.

The design of these experiments and the resulting scoring into dichotomous or binary categories, presented apparent difficulties regarding the suitability of the ANOVA technique for these data. Two of the basic assumptions underlying this technique are not met with binary data: (a) that the distribution is continuous and (b) that the data are normally distributed. In addition, some designs may violate assumptions of equal cell variances and inter-subject symmetry. Fortunately, this situation has been studied by statisticians and considerable support for this particular application was found in the literature.

One of the first mentions of the use of the F-test with binomial data came from Cochran (1950). Although much of the Cochran monograph dealt with the application of chi-square to binomial data, he stated that "... it is not obvious whether F or X^2 is more sensitive to the assumption of normality. Inclusion of the F-test in testing binomial data is also worthwhile in view of the widespread interest in the application of the analysis of variance to non-normal data."

More recently, Seeger and Gabrielson (1968) extended Cochran's work in applying the F-test to dichotomous data in a large number of computer-simulated experiments involving both treatment of main effects and interactions with subjects. In general, they found that the F-test gave at least as good results as the Q-test, especially for testing interactions. In most cases, about 10 subjects provided adequate results although when "... strong deviations from symmetry in the covariance matrix is (sic) suspected .... a larger number of subjects is required, and the results must be interpreted with caution."

The next year, Hsu and Feldt (1969) repeated much of this work with similar results. These investigators emphasized advantages of the ANOVA over the ^{2} test when the sample size was small, when the study involved more than one factor, or when the primary interest is in the differences among means rather than the variances of the populations. Although these investigators used designs with only one or two variables, Hsu and Feldt (1969), and also Edwards (1972), extend the application of the general conclusions to factorial designs. These studies seem to provide sufficient justification for the application of ANOVA to the dichotomous data of these studies.

REFERENCES - APPENDIX B

Cochran, W. G. The comparison of percentages in matched samples. *Biometrika*, 1950, 37, 256-266.

Edwards, A. L. *Experimental Design in Psychological Research* (4th ed.) New York: Holt, Rinehart and Winston, 1972.

Hsu, T. C., & Feldt, L. S. The effect of limitations on the number of criterion score values on the significance level of the F-test. *American Research Journal*, 1969, 6, 515-527.

Seeger, P., & Gabrielson, A. Applicability of the Cochran *Q* test and the *F* test for statistical analysis of dichotomous data for dependent samples. *Psychological Bulletin*, 1968, 69, 269-277.